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# INVESTIGATING SOCIAL INTERACTION DYNAMICS AS A MULTI-LEVEL PHENOMENON

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**Figure 1** A colourful note taken during a Mindful Researchers meeting (see *Epilogue 2*), which I joined from Copenhagen, where I accompanied Joe Dumit to several meetings with art-science collaborators. The image captures my basic approach as well as insights I gained from my doctoral work. Photograph taken in the family holiday apartment in Nebel, Amrum, Northern Sea, where many words of this thesis were written.

# Investigating social interaction dynamics as a multi-level phenomenon

*Annika Lübbert*

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## Statement of motivation

Before I present my doctoral research, I'd like to describe the lines of motivation that run through this thesis. I also want to express my curiosity for what you, the reader, find in this work, and my sincere wish that it be inspiring and useful to your collaborative and research endeavours.

*The value of multiple perspectives*

The work presented in this thesis acknowledges multiple aspects of social cognition, or multiple surfaces on which social interactions take place - from the spaces we inhabit, to mental and embodied movements we make as we interact with others. The experimental paradigms I developed therefore made use of both quantitative and qualitative methods of observation, and considered several kinds of data relevant to interactive experience and behaviour: what was alive for participants? How did they behave in the interactive coordination game? What personality did they bring to the task? My work then generated comprehensive frameworks of analysis that integrate answers to these questions.

I also collaborated on initiatives to bring awareness of experience, body and space to our work as researchers, and experimented with forms of meeting and organisation that invite the differences in perspective of individuals and professionals from a variety of backgrounds.

*Practicing what you preach - preaching what you practice*

In several collaborative projects, I applied my scientific background (embodied and enactive cognition) to my practice as a researcher: what could experiments and research collaborations look like that embrace and work with the environment, our embodied movement, social interaction dynamics and our ongoing experience as inextricable? I consider the experience I gained from this applied work central to my development as an academic researcher of embodied social cognition.

*Pillars of (inter-)personal engagement*

At the end of my doctoral work, I identify three pillars of interpersonal engagement: context, balance and integration. These themes emerged from my empirical findings as well as my applied work. They also describe my research interests: finding ways to include and learn about context, balance and integration in my research was central to completing this body of work.

# CHAPTER 1: GENERAL INTRODUCTION

Social interactions pervade our daily life - most things we do, want or need involve others. Encounters with other people are not only pervasive but remarkably complex: situated between conventions, our personal and embodied needs and abilities, as well as the affordances presented by our (social and physical) environment, they can follow a seemingly unpredictable course - simple exchange with a stranger can bring up heaps of emotion, make or ruin our day or even change the course of years to come, if we happened to meet a future life or business partner.

The present work approaches the complex web of mutual influence that is social behaviour from a personal and embodied angle: what exactly do we experience in a social interaction that we would describe as engaging or successful? What kind of movement can support an engaged interaction dynamic?

In the following paragraphs, I first present the theoretical background that informed my work: the young tradition of embodied and enactive cognitive science - an interdisciplinary field with roots in philosophy, biology and computer science. Next, I describe the two laboratory settings I used to investigate social cognition as a multi-level sense-making process: the BallGame and the Sonified MirrorGame, both of which combine an engaging coordination task with elaborate data recording techniques. The introduction then takes a more personal turn: before I close, by equipping the reader with a clear roadmap to navigate the remainder of this thesis, I motivate my engagement in collaborative initiatives to bring embodied and relational awareness to my academic work.

## Theoretical Background

Research on **embodied and enactive cognition** investigates mental capacities with an emphasis on the role of the body and its ongoing self-maintaining and self-transforming relations with the environment. In this view, language, memory, reasoning or decision making become activities that involve mental and central nervous system activity *as well as* other tissues and organs of our body, spontaneous interactions with the environment, as well as the habits and routines that orient us in larger physical and social contexts. Within the wide domain of research on embodied and enactive cognition, my doctoral work was especially inspired by accounts of participatory sense-making (De Jaegher & Di Paolo, 2007) and sensorimotor contingencies (O'Regan & Noe, 2001). Both theoretical accounts emphasise participation in rhythms and repertoires that we share with our physical and social environment. In particular, **participatory sense-making** (De Jaegher & Di Paolo, 2007; De Jaegher et al, 2010, 2017) focuses on the motivated and self-generating yet precarious nature of social engagement: based on the drive to maintain established habits (boundaries, ways of thriving or being recognised by a larger group/system), interactions between cognitive organisms and their environment are inherently meaningful (motivated, self-generated/-ing). At the same time, neither organisms nor their cognitive activities are independent: they always involve the wider context of enabling factors provided through their embodied and social relations, which organisms must maintain in order to survive - highlighting the emergent nature and autonomy of organism-environment interactions. The concept of **sensorimotor contingencies** (O'Regan & Noe, 2001; Engel et al, 2013), in turn, centres on the role of regularities and interdependence at the level of basic sensory perception and action. It presents perception as an *activity* that orients us towards familiar modes of exploring and thus recognising our environment. As part of my work on this thesis, I contributed to an extension of the basic concept of sensorimotor contingencies into the social domain (Lübbert et al, 2021; *Chapter 2* of this thesis). In particular, we proposed that coupling modes - dynamics of mutual sensitivity and response - can provide a unifying framework of analysis across neural, physiological, interpersonal and situated (environmental, material) forms of sense-making. This view not only suggests the equal relevance of these distinct levels of organisation, but also that similar dynamics of mutual influence may be at play within and across each of them. Such an approach resembles the emphasis on self-organised pattern formation in the field of coordination dynamics - in particular the concept of meta-stability, which models stable dynamics as a combination of segregative and integrative tendencies (Tognoli and Kelso, 2014). It also shares similarities with the joint action model forwarded by Knoblich and Sebanz (2008), which proposes that flexible social behaviour derives from increasingly complex forms of organisation bound together in shared intentionality (see also, Rietveld et al, 2013). The unique character of the theory of social sensorimotor contingencies lies in its application across domains (phenomenology, neurophysiology, movement coordination, social cognition) as well as its original focus on interpersonal movement dynamics and social experience as the place to learn about principles of interdependent sense-making. *Chapter 2* presents a more detailed account of social sensorimotor contingencies and as such a comprehensive overview of the theoretical background that informed this thesis.

**Empirical work**

In *Chapters 3 and 4*, I go on to introduce the **laboratory setups** I designed to study the relationship between interpersonal movement dynamics and social experience: the BallGame (*Chapter 3*) and the Sonified MirrorGame (*Chapter 4*). Both paradigms involved continuous sensing and acting between participants, prioritised personal engagement and motivation, included in-depth experience assessment and generated highly resolved records of movement and gaming behaviour. They also assessed (or manipulated) contextual factors that might have influenced the interaction dynamic. These included personality traits, information availability in the game (shared versus complementary between players), the sensory feedback modality (vision, sound or both) as well as the instructions given to participants about their role in the interaction (lead / follow versus jointly improvise). Of note, I performed individual interviews with participants to learn about their overall experience of the game as well as moments they found particularly meaningful or remarkable. This helped me identify what mattered most to participants' social engagement. The analysis of participant reports also provided an important background against which to interpret our results from quantitative approaches to model game concurrent experience ratings as a function of behavioural records. They also motivated specific follow-up analyses of our game concurrent data. As such, I generated extensive records of two people engaged in a social interaction game. By striving for ecological validity (participant engagement) and the integration of measures across levels of observation, my approach responds to methodological challenges in research on interpersonal coordination (see e.g. Cornejo et al, 2017). Both experimental designs were influenced by recent empirical work in embodied and enactive cognition, most prominently by work on joint reaching (Vesper et al, 2016), highly reduced spaces for social encounter such as the perceptual crossing paradigm (Auvray & Rohde, 2012; Froese, Iizuka & Ikegami, 2014) as well as mirror or shadowing games (Llobera et al, 2016; Noy et al, 2011; Feniger-Schaal et al, 2018).

*The BallGame*

In the BallGame (*Chapter 3*), two players bent and flexed their index fingers to steer a virtual ball around obstacles towards as many targets as possible. *Figure C1.1* presents the laboratory and game environment. With this paradigm, I generated a rich dataset that comprises records of personality traits, subjective experience, gaming behaviour, finger- and eye-movement as well as brain activity[1]. As part of my work on the BallGame - which I realised in close collaborative exchange with Florian Göschl, a post doc at the institute - I implemented an analytic framework capable of integrating results identified at the level of experience, movement and gaming behaviour. In particular, based on my in-depth exploration and pre-processing of the behavioural data, as well as Florian's exploration of suitable modelling techniques and additional measures of movement coordination, we settled on an approach that prioritises the prediction of experience ratings from the remainder of the data, and contrasts observations over different scales of time and joint play conditions (see *Chapter 3A*). Based on qualitative analyses of individual participant interviews, I further created an overview of participants' lived experience of social interaction

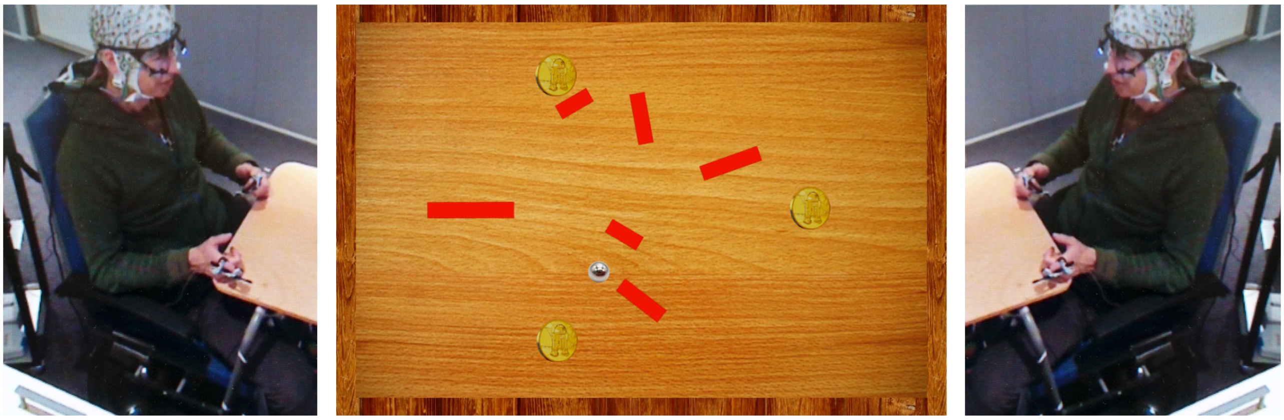

**Figure C1.1** Illustration of the BallGame experiment. **(left & right)** Lab camera view on a participant engaged in the game, equipped with bimetal sensors, eye-tracking goggles and EEG cap. **(centre)** Screenshot of the game environment - the ball (metallic circle) is steered around obstacles (red bars) to reach as many targets (golden coins) as possible, before the constellation of target and obstacle position changes in the next trial. For an animated illustration of the game dynamics, see https://vimeo.com/717215340.

[1] Note that eye tracking data and brain activity recordings were not included in the analyses presented in this thesis.

through the BallGame. This in-depth subjective experience assessment led to follow-up analyses on the impact of targets and obstacles on interpersonal movement coordination, within-trial changes in coordination and gaming behaviour, as well as differences among players concerning the shift from joint to individual play (see *Chapter 3B*).

*The Sonified MirrorGame*

In the Sonified MirrorGame (*Chapter 4*), I presented participants with a yet simpler but more open-ended task: equipped with pen, tablet and a virtual line along which to move, participants were told to produce coordinated movement and interesting sounds together. See *Figure C1.2* for a view of the laboratory and game environments. Under different conditions - in visual, audiovisual or auditory play, as well as under the instruction to lead and follow, or to jointly improvise - participants explored moving in this highly reduced but challenging space. In particular, a rich interactive movement sonification (co-designed by modern composer Pedro Gonzàlez-Fernàndez and myself) expanded the interactive domain to an additional sensory modality: as participants moved together in close proximity, they generated orchestra sounds - when they moved further apart, rhythmic beat sounds directed them to the position of their partner. Of note, to realise in-depth assessment of participants' experience, I conducted individual as well as joint interviews with participants and asked them to complete an innovative 'map of emotions' task: participants placed magnets labeled with sense-qualities (warm, nervous, comfortable, curious, etc) around the shape of a body in order to reflect on and report their current state. As for the BallGame, my analyses first focused on predicting participants' experience ratings from parameters that capture their movement coordination, personality differences as well as the interaction context (sensory feedback modality and leadership instructions), and used analyses of variance to compare measures of movement coordination over

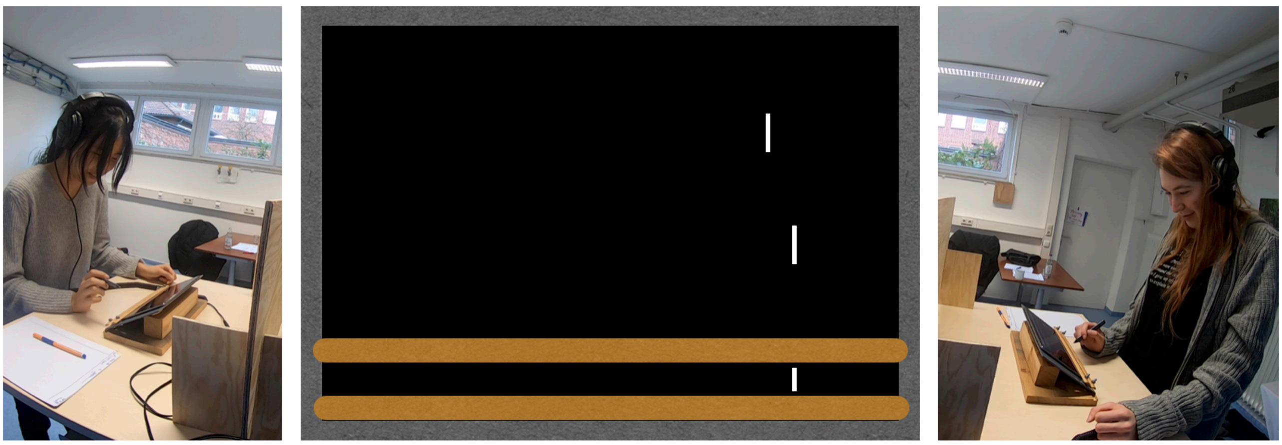

**Figure C1.2** The Sonified MirrorGame. **(left & right)** Two participants engaged in the game, quipped with headphones, pen and tablet, as well as a sheet to take notes on their experience after a trial. **(centre)** View of the tablet screen during the game. Players move the bottom avatar, situated between two wooden bars placed on top of the tablet, to coordinate with their partner (top avatar). Note: in the auditory-only condition, the two top bars are not visible. See https://wearethefuture.net/the-sonified-mirrorgame/ for sound recordings from example trials.

time and across game conditions (see *Chapter 4A*). I again proceeded by generating an overview of participants' lived experience of social engagement in the Sonified MirrorGame (see *Chapter 4B*). The thematic content analysis provided a rich description of the quality of attention and mode of play under the different sensory feedback conditions. It also helped me identify a theme present across different levels of observation: a dual balance that players sought between familiar and exploratory behaviour, as well as between their own and their partner's interests.

**Methodological development and applied work**

Before I close the introduction with a short overview of the following chapters, I bring in a perspective from science and technology studies to clarify a central undercurrent to my doctoral work and approach to academic research.

I believe that cognitive scientists are acutely aware of the complex set of processes that influence human behaviour and experience at any moment. It forms part of our education and know-how to *exclude* and control for them as confounding factors in our experiments. Statistical analysis of ideally hundreds of instances of a highly particular behaviour or experience allows us to assess the probability of precisely formulated and operationalised hypotheses. However, the same constraints that maximise precision around a given hypothesis or distinction, blind our observation to *anything but* said distinction. With this caveat in mind, how can we be sure that our questions and hypotheses, or the tools we use to pose and test them, are actually (the most) relevant to the process or phenomenon we seek to study? This tension is sharply outlined by Joseph Dumit (2014, 2016). Dumit (2016) describes the reifying (self-fulfilling) effect of methodological and visual conventions (e.g. the use of flow charts to represent patterns of brain activity) on the type of problem statements addressed in the cognitive neurosciences: by developing and discussing hypotheses about neuro-cognitive function in the form of isolated boxes connected by arrows, and by using software that assumes connected hubs of activity in order to generate images of brain activity, researchers *prescribe* circuit-like organisation onto the brain. While it is certainly possible and stimulating to imagine the brain as a circuit, the point is that research conventions reinforce specific ways of understanding and investigating a phenomenon. Dumit's (2014) analyses also suggest alternative possibilities: on the basis of Lettvin and colleagues' (1959, 1960) remarkable work on the frog visual system, as well as Colby (1963, 1975) or Abelson's (1963) early simulations of pathological mental states, Dumit outlines a more **plastic scientific method**. Marked by playful relationships, educated instincts and curiosity for what *it* cares about - be it a neuron, brain region, psychological disorder or social interaction dynamic - researchers 'abduct' the most suitable method *from their phenomenon of interest*, instead of deducing it from theory or inducing it from data (Dumit, 2014). Lettvin and Colleagues (1959), for example experimented with a wide array of visual stimuli and moved them by hand, flexibly responding to sound signals that represented the neuronal activity they invoked in the frog. In an open-ended approach that refrains from early commitment to extensive and systematic stimulation, recording or analysis, the researchers thus remained adaptable to what was called forth by their subject of study - and hence open to be surprised by their research (Dumit, 2014). Methods then do not reduce problems of puzzling complexity to (what is observable through) regimes of systematic repetition, but open doors towards these phenomena by engaging us in sensitive forms of assimilation.

In hindsight, I find these remarks spot on, particularly with respect to my research field and question: to the best of my knowledge, engaged social interactions 'care about' rich, multi-level opportunities to relate, to be moved, recognised and propelled onto new ways of understanding - in short: co-creative sense-making processes that involve and transform who we are. How to make space for these 'preferences' of engaged social interaction in laboratory settings? Over the course of my doctoral work, I pursued two strategies to tackle this concern. First, I sought to grant space to participants' perspective and interest - to enhance their freedom and autonomy to co-create an engaged interaction dynamic - from the conception of experimental designs to the writing up of results. Second, I focused on the modalities available to researchers for exploration and conceptual development. For example, I did not want to leave my embodied and social sensitivity behind as I academically investigated social interaction dynamics. In search of possible solutions, my empirical work emphasised **participant participation**: I integrated in-depth experience assessment as equally relevant to behavioural, movement and physiological observations. In particular, I used methods that invite participants to contribute from their perspective, as well as to notice embodied and interactive dimensions of their experience. I also found and created spaces to **implement concepts** from my theoretical background (embodied and enactive cognition) in the way I work as a researcher: I hence developed skills and tools to ground research collaborations and academic organisation in embodied, situated and relational practice. The *Epilogue* to this thesis presents the two most extensive projects that emerged from this line of investigation. First, the *Playful Academic* (*Epilogue 1*), which delivers a protocol of scores to facilitate collaboration in teams of researchers. The scores direct researchers' attention to their cognitive-affective states, their body, physical environment, social interaction dynamics and the concepts or other tools they use in their respective discipline. Besides implementing principles from embodied and enactive cognition, the Playful Academic argues that a balance between diverse modes of sense-making, as well as fun and engagement lead to a more liveable research practice and more objective science. Next, the *Mindful Researchers* (*Epilogue 2*) are an international initiative and network that offers regular (online) meetings for dialogue and shared practice to ground our professional work in embodied and relational skills. In weekly meetings with the core group of organisers, we develop the skills, trust and meeting formats we need to integrate embodied and co-creative practices into our work. Open to a larger community, we offer (bi-)monthly events that follow one of our meeting formats and involve researchers and other professionals in shorter and longer term participatory processes. Over the past year and a half, we have presented our work and facilitated workshops at scientific conferences. Recently, we started to engage in research and written reflections on our collaborative process. A contemplative attitude, attention to the body and our relations to each other and the environment are essential ingredients of both projects.

**Summary and outlook**

To recap and provide the reader with a clear roadmap to navigate this thesis: in the following chapters, I first introduce the theoretical background that set me out on the investigation of interpersonal movement coordination as a key ingredient of social engagement. In particular, I motivate the concept of social sensorimotor contingencies, which integrates the (presumably) higher level cognitive functions required to navigate interpersonal relations and social conventions, with our basic perceptual-motor activity (*Chapter 2*). Next, I introduce the two laboratory experiments I conducted to generate multi-level observations of simple but engaged social interaction - the BallGame (*Chapter 3*) and the Sonified MirrorGame (*Chapter 4*). These experiments focus on the relationship between interpersonal sensorimotor coordination and engaged social interaction, but equally consider the influence of further contextual factors. My analyses show that participants' game concurrent experience ratings can be predicted from a combination of interpersonal movement, gaming behavioural and personality measures, and that both experience and movement coordination are influenced by the interaction context. Note that both chapters are subdivided into a part A - the main presentation of the experiment as well as quantitative analyses of game concurrent data, a part B - complementary analyses of in-depth participant interviews (and follow-up analyses motivated by our findings from the interviews), and a part C - supplementary materials to parts A and B. Finally, in *Chapter 5*, I highlight and discuss the most relevant findings from my empirical work, emphasising in particular potential future lines of investigation. I also create links to the applied projects I engaged in to strengthen embodied and relational practice in collaborative research contexts - the Playful Academic and the Mindful Researchers, both of which are presented in more detail in the *Epilogue*.


**Figure C1.3** A colourful note drawn while listening to a recording of myself reading the text of the introduction. Photograph taken at the edge of the wooden path through the dunes, Nebel, Amrum.

# CHAPTER 2: THEORETICAL BACKGROUND - SOCIAL SENSORIMOTOR CONTINGENCIES

This chapter presents the theoretical background of this thesis: social sensorimotor contingencies (socSMCs). Forming part of the larger field of embodied and enactive theories of cognition, socSMCs present a theory in which basic perceptual-motor organisation is closely intertwined with presumably higher levels of cognition - including our behaviour in social encounters and as sophisticated members of groups, cultures and places. As such, this theory motivates the study of social interactions at multiple levels. In particular, it highlights interpersonal movement coordination and the experience of social engagement as key entry points into the complex set of relations at play when we think and act together. Importantly, the work presented in this chapter is directly related to the - equally named - socSMCs research consortium that most of my doctoral work contributed to, a European (2020 Horizon) network of researchers in cognitive neuroscience, information theory and robotics.

**Chapter 2** presents a theory and hypothesis article published in the frontiers research topic *Sensorimotor Foundations of Social Cognition*[2]. The research topic was coordinated by the principal investigators of the socSMCs research consortium and marked the final joint effort of this network. In the article, we outline the socSMCs concept, emphasising in particular the study of low-level interpersonal sensorimotor processes as well as higher-level behavioural coordination dynamics as promising strategies to understand social engagement. We further situate the socSMCs concept among related theories of embodied joint action, and discuss implications for psychological treatment and human-robot interactions.

Lübbert, A., Göschl, F., Krause, H., Schneider, T.R., Maye, A. and Engel, A.K. (2021). Socializing Sensorimotor Contingencies. *Front. Hum. Neurosci.* 15, 624610 https://doi.org/10.3389/fnhum.2021.624610

Author contributions: AE, AM, and AL developed the core ideas of the concept discussed in this review. All authors contributed to the writing of this article.

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[2] Find the research topic and article at https://www.frontiersin.org/research-topics/9316/sensorimotor-foundations-of-social-cognition#articles, and https://www.frontiersin.org/articles/10.3389/fnhum.2021.624610/full, respectively.

## Chapter 2

## Socializing Sensorimotor Contingencies


### Abstract

The aim of this review is to highlight the idea of grounding social cognition in sensorimotor interactions shared across agents. We discuss an action-oriented account that emerges from a broader interpretation of the concept of sensorimotor contingencies. We suggest that dynamic informational and sensorimotor coupling across agents can mediate the deployment of action-effect contingencies in social contexts. We propose this concept of *socializing sensorimotor contingencies* (socSMCs) as a shared framework of analysis for processes within and across brains and bodies, and their physical and social environments. In doing so, we integrate insights from different fields, including neuroscience, psychology and human-robot interaction. We review research into dynamic embodied interaction and highlight empirical findings that consider the important role of sensorimotor and personal engagement in social contexts. Furthermore, we discuss links to closely related concepts, such as enactivism, models of coordination dynamics and others, and clarify differences to approaches that rely heavily on mentalizing and high-level cognitive representations. Moreover, we consider conceptual implications of rethinking cognition as social sensorimotor coupling. The insight that social cognitive phenomena like joint attention, mutual trust or empathy rely heavily on the informational and sensorimotor coupling between agents may provide novel remedies for people with disturbed social cognition and for situations of disturbed social interaction. Furthermore, our proposal has potential applications in the field of human-robot-interaction where socSMCs principles might lead to more natural and intuitive interfaces for human users.


### Introduction: grounding cognition in action

In the cognitive sciences, we currently witness a ‚pragmatic turn' away from the traditional representation-centred framework towards a paradigm that focuses on understanding the intimate relation between cognition and action (for review, see Engel et al., 2013a). Although such an action-oriented paradigm has been supported by many proponents over the years (e.g. Varela et al., 1991; Clark, 1997; Noë, 2004), it has only recently begun to have a notable impact in the cognitive sciences (see Menary, 2010; Engel, 2010; Engel et al., 2013a; Durt et al., 2017). The basic concept is that cognition should not be understood as a capacity of deriving world-models, which then provide a detached database for independent thinking, planning, and problem solving (Schilbach et al., 2013). Rather, it is emphasised that cognitive processes are so closely intertwined with a body in action that cognition is best understood as enactive, as a form of situated practice rather than disembodied mentalizing (Varela et al., 1991; Noë, 2004; Engel, 2010). Cognition, on this account, is grounded in a pre-rational being-in-the-world based on sensorimotor skills for real-life situations, and core aspects of cognition, such as sensing, perceiving or understanding, become inseparable from doing (Varela et al., 1991; Clark, 1997; O'Regan and Noe, 2001; Noë, 2004). This agrees with phenomenological claims about intricate links between our different senses and the body's role in thinking (Merleau-Ponty, 1962, 1963), modern anthropological studies of the process of knowledge-making (Myers and Dumit, 2011; Myers, 2015) and recent calls to look beyond analytic ways of knowing (De Jaegher, 2021). Drawing on pragmatist and phenomenological traditions, numerous recent authors have explored the implications of defining cognition as embodied action (Varela et al., 1991; Clark, 1997; Noë, 2004; Pfeifer and Bongard, 2006; Menary, 2010; Engel, 2010; Sheets-Johnstone, 2011; Engel et al., 2013a).

Immediate precursor to the concept proposed in this article, the ‚sensorimotor contingency theory' (SMCT) put forward by O'Regan and Noë (2001) centers on the notion that perception and cognition can only be understood by considering their inherent action-relatedness. In this framework, sensorimotor contingencies (SMCs) are defined as acquired law-like relations between movements and associated changes in sensory inputs that are continuously probed and refined as we orient in the world. The formation of SMCs shows to be highly relevant in cognition (O'Regan and Noe, 2001; Engel et al., 2013a; Maye and Engel, 2013). SMCs are acquired through the agent's actions, and are deemed constitutive for perceptual processes. For instance, according to the SMCT seeing cannot be understood as the processing of an internal visual representation; rather, seeing corresponds to being engaged in a visual exploratory activity, mediated by knowledge in the form of SMCs. This active nature of sensing has been emphasised by other approaches as well. However, the concept of SMCT is more radical: it considers action a necessary prerequisite for perception, not just as an output capacity that supports, or interacts with, perceptual processing. Of note, this account does not postulate a unidirectional impact of motor systems on perception but, rather, is compatible with the notion of dynamic sensorimotor interactions in reentrant processing loops (Engel, 2010). There is increasing evidence from work in neuroscience, psychology and robotics supporting the SMCT perspective (e.g., Frith et al., 2000; Maravita and Iriki, 2004; Gallese and Lakoff, 2005; Schubotz, 2007). For instance, neuronal response properties in sensory brain regions strongly depend on action context (Gallant et al., 1998), perceptual scene segmentation is facilitated by the active use of the objects (Bergström et al., 2011), and processes like attention and decision-making have been shown to be strongly related to activity of motor regions (Moore et al., 2003; Donner et al., 2009). Thus, SMCs have been proposed as a framework to define object concepts and action plans, suggesting that the mastery of sensorimotor contingencies facilitates goal-oriented behavior (Maye and Engel, 2011, 2012; Högmann et al., 2013; Engel et al., 2013a). This implies that SMCs can be relevant over variable time scales beyond the correlation between movements and the immediate changes in sensory inputs, which are the focus of the original SMCT (O'Regan and Noe, 2001).

In keeping with this pragmatic turn, the concept discussed here suggests an action-oriented framework for social cognition in biological and artificial agents. Our proposal is to ground even complex modes of social interaction in the continuous dynamic coupling between agents and their environments. Successful social interaction, thus, does not come about exclusively through the theories that a detached observer holds about the intentions, beliefs and personalities of other agents (Carruthers and Smith, 1996) but – as we will argue – to a substantial extent via the formation and management of shared rhythms and patterns at the level of embodied sensorimotor dynamics. As will be discussed in greater detail below, our proposal is related to and inspired by other action-oriented concepts of social cognition that have emphasized the relevance of coordination dynamics (Tognoli and Kelso 2014), of socially salient movement patterns (Lindblom and Ziemke, 2006), motor mimicry (Wang and Hamilton, 2012) and joint embodied action (Sebanz et al., 2006). Notably, earlier proponents of an enactive view of social cognition have suggested that even complex modes of social interaction may be grounded in basic sensorimotor patterns that enable the dynamic coupling of agents (De Jaegher et al., 2010, 2017). Supporting this view, evidence is available that interactive sensorimotor dynamics provide substantial clues to social understanding (Di Paolo and De Jaegher, 2012), give rise to high-level processes such as shared intentionality (Sebanz et al., 2006) and empathy (De Waal and Preston, 2017), and are highly relevant for interpersonal affiliation, trust and prosocial behavior (Keller et al., 2014).

In the concept proposed here, the notion of SMCs is substantially broadened beyond its original scope (O'Regan and Noe, 2001) to include the learning and deployment of action-effect predictions on longer time-scales and more complex levels of processing. Previously, we have suggested that SMCs can be deployed to acquire object concepts and to achieve prediction and action planning, e.g., in obstacle avoidance tasks (Maye and Engel, 2011, 2013). Here, we propose that the relevance of SMCs is not limited to sensorimotor processing of the individual, but extends into the effective interactions between agents in social context. Since in our view, these socially shared contingencies are constitutive for social cognition, the influence of others cannot be discarded when seeking to explain individual cognition or behavior: individual and collective processes become irreducibly linked. In the following, we use ‚socSMCs' as a shorthand for the proposal to ground the development and instantiation of social cognition in shared action-effect contingencies.

**Unpacking the socSMCs concept**

The socSMCs concept departs from the classical notion that presumed higher levels of cognition (e.g., self-recognition, perspective-taking, planning, complex reasoning) might differ fundamentally from presumed basic levels of sensorimotor processing (such as perception, multisensory integration, or motor coordination). This aligns well with the notion that both domains of cognition rely on common neural architectures and computational principles (Keller and Mrsic-Flogel, 2018), and evidence that brain regions embodying complex cognitive functions do not differ in principle from modules involved in more basic functions (Douglas and Martin, 2004). Where classical cognitivism might ask, ‚How would we understand the world, other than by generating models about it?', the socSMCs concept acknowledges the role of abstract reasoning, but puts equal emphasis on collective sense-making processes that arise only in relation to our physical and social environments. Thus, the socSMCs concept suggests in principle shared neural mechanisms for all our ways of engaging with our environment, and views structures and activities outside of our central nervous system as essential for our cognitive abilities (Clark and Chalmers, 1998).

A key assumption in the concept of socSMCs is that agents deploy learned action-effect contingencies in social contexts to anticipate outcomes of their own and others' actions (Brown and Brüne, 2012): I am the initiator of change in the (social) world, and change in the world can be directed at me. Such action-effect contingencies closely relate to the more basic framework of SMCs described above where, e.g., stable perception of the world comes about because we actively learn patterns of correlations between our actions (eye movements) and the ensuing effects (changes in the retinal inputs). We propose that agents' ability to anticipate and coordinate with others at linguistic and abstract levels may derive from their learning of motivated and embodied action in the world. In other words: how we orient in social contexts is very much an extension of how our body orients in the world. This includes social entrainment, defined by the sensorimotor or informational coupling between agents, and social engagement, i.e., the experience of connectedness or relatedness to other agents. The socSMCs concept predicts that both are grounded in the acquisition and deployment of action-effect contingencies. Further, we assume that both the experience of social engagement and our participation in social entrainment are situated within particular physiological, cultural and environmental contexts, within which they emerge and onto which they also feed back.

Another central assumption in socSMCs is that social interaction can best be conceptualised in terms of dynamic coupling at different scales (Hasson et al., 2012; Engel et al., 2013b, Hasson and Frith, 2016; Keller et al., 2014; Kelso, 2019). We propose to differentiate three levels of complexity of social coupling, reflecting different stages across which interactions are established in a multi-agent system (Figure C2.1). We term these ‚check SMCs', ‚sync SMCs' and ‚unite SMCs', respectively, to denote that they may correspond to distinct stages, or modes, of social entrainment. These levels are best conceived as points on a continuum, with potential co-occurrence of modes of relating. Across these three levels of socSMCs, coupling is established over an increasing set of degrees of freedom of the interacting multi-agent system. At the first level, check SMCs involve unidirectional coupling, one agent predicting another agent's actions or the interaction between several other agents. Behaviorally, this may lead, e.g., to entrainment of one agent to a group of other agents. At the next level, sync SMCs enable bidirectional coupling, with both agents mutually sharing, attending to and predicting each other's sensorimotor actions. This reciprocity may then lead to genuine interactions and mutual entrainment of behavior, facilitating cooperation, joint attention, turn-taking, and shared action goals. At the third level, we suggest unite SMCs as a hypothetical coupling mode that may promote group-related, multidirectional coupling. Unite SMCs might be characterized by the emergence of interaction patterns that cannot fully be explained by the pairwise interactions among the group members, and attain a certain amount of autonomy over them (see also De Jaegher et al., 2017). For brain networks, there is evidence to suggest the occurrence of such higher-order coupling modes. Thus, it has been shown that cortical spike activity contains triple or quad correlation patterns more often than predicted from pairwise correlations, and that such higher-order patterns relate to information encoding and behavior (Montani et al., 2009; Shimazaki et al., 2012). We hypothesize that similar high-order dynamics might occur for social coupling modes. Such group dynamics may play a key role in group mental states, shared habits, and group affect. At this level, the emergent macroscopic pattern of multi-agent coupling may be stable enough to provide a new source of entrainment for individual agents, beyond the impact of pairwise interactions, as has been observed, e.g., in studies on collective dance improvisation (Himberg et al., 2018).

We suggest that the three levels of SMCs may take effect over different temporal and spatial ranges, depending on the setting and the mechanisms involved in the interaction. In this context, it may be useful to distinguish between ‚proximal' and ‚distal' interactions (Figure C2.2) (cf. Pezzulo et al., 2019). While proximal interactions involve direct physical contact and sensorimotor coupling, distal interactions promote social entrainment by information flow between agents without direct physical coupling. Both proximal and distal social coupling abound in everyday life. Real-world scenarios involving proximal interactions with direct sensorimotor coupling include, for instance: greeting habits, like a handshake or a hug, where mutual dynamic entrainment is highly relevant for signaling the quality of a social relation; joint lifting or carrying of heavy objects that cannot be handled by one person alone, e.g. when moving a household; or dancing together as a couple, where sensorimotor coupling creates the synergy and togetherness enjoyed by the dancers. Examples for distal SMCs in social context include: social mimicry, i.e., an unvoluntary tendency to imitating or synchronize with postures and gestures of a conversation partner; team sports, ranging from synchronized swimming to coordinated group dynamics in volleyball or soccer; performance of musical ensembles engaged in joint improvisation, or the informational coupling between conductor and orchestra through embodied movement cues. Of note, distal interactions based solely on informational coupling can also take effect in fully virtual settings such as, e.g., in online gaming or in a video conference, provided that the agents can engage in meaningful action-effect contingencies.

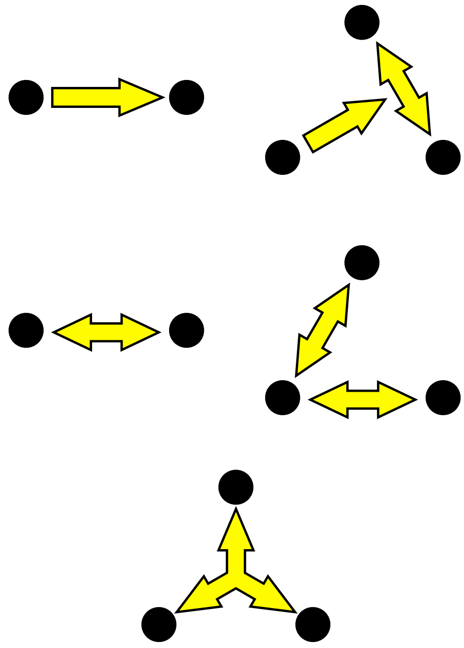

**Figure C2.1:** Three hypothesized levels of SMCs in social interaction: **(Top)** Check SMCs may be mediated by unidirectional coupling between two agents (left) or from one person to other interacting agents (right). **(Middle)** Sync SMCs involve reciprocal coupling between two or more agents. **(Bottom)** Unite SMCs are conceived as emergent higher-order correlation patterns in the group dynamics.

The socSMCs concept treats individuals engaged in an interaction as one system. It therefore requires methods suited for the analysis of complex systems, since they may best capture the reciprocal adaptation that underlies coordination and communication (Fusaroli and Tylén, 2016; Gallotti et al., 2016). To this end, we suggest that measures used to quantify coupling within brains (for review, see Engel et al., 2013b) could prove equally useful to quantify the degree of coupling between individuals and their environment. Dynamic functional coupling is considered a key feature of brain activity, which exhibits rich spatiotemporal patterning and strongly modulates cognitive processing. Measures used to quantify functional coupling in the brain include coherence, power envelope correlation, information-theoretic measures or multivariate autoregressive models (see, e.g., Engel et al., 2013b, Hutchison et al., 2013; Bastos and Schoffelen, 2015). Much of this coupling is intrinsically generated, that is, not imposed by entrainment to an external stimulus or movement, but emerging from the connections within brain networks. There is clear evidence for two distinct types of coupling modes, which seem to reflect the operation of different coupling mechanisms (Siegel et al., 2012; Engel et al., 2013b). One type arises from phase coupling of band-limited oscillatory signals, whereas the other results from coupled aperiodic fluctuations of signal envelopes. These two coupling modes (phase coupling vs. envelope coupling) differ in their dynamics, their spatial distribution, the time scales over which they operate and they likely support different functions (Engel et al., 2013b). Envelope coupling might reflect co-activation of regions on slower time scales and, thus, might facilitate the participation of brain areas in an upcoming task. Phase coupling, in contrast, represents coupling on faster time scales which presumably generates highly specific dynamic links within networks defined by envelope coupling. As part of the socSMCs concept, we propose that these intrinsic coupling modes are complemented by extrinsic coupling modes, i.e., coupling patterns that reflect the interaction of the brain with the body and its environment, including the social context (Figure C2.2) (cf. Hasson et al., 2012; Hasson and Frith, 2016; Pezzulo et al., 2019). We propose that such extrinsic coupling modes may play a key role in enabling coordinated interaction of multiple brain systems with both body and environment, and that they may be particularly relevant for interaction with the social world. These extrinsic coupling modes should not only become evident at the level of behaviors or movement kinematics, but also give rise to inter-brain coupling in settings where neural signals

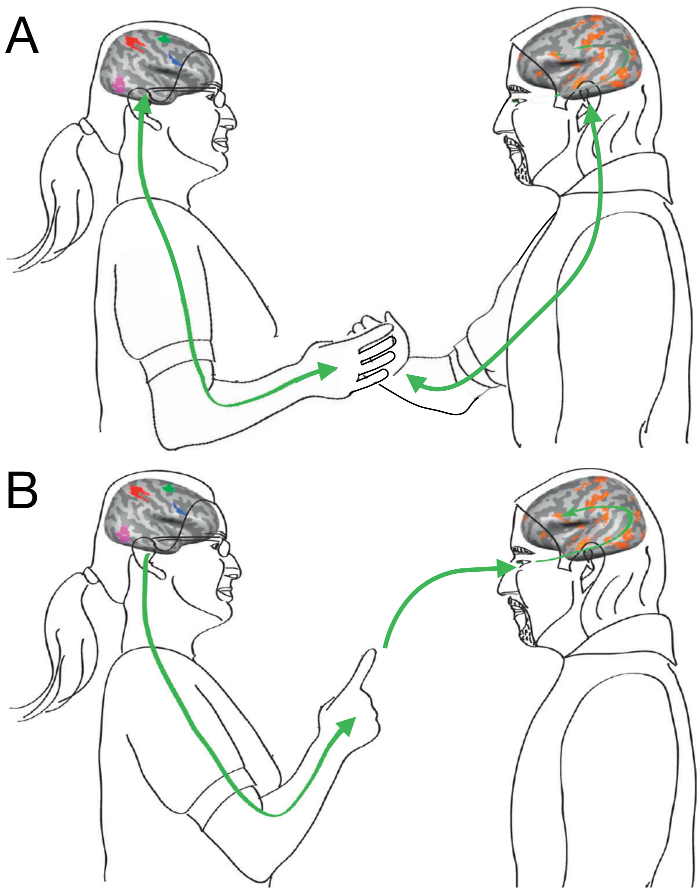


**Figure C2.2:** Social interactions may involve proximal and distal types of SMCs. **(A)** Proximal sensorimotor coupling through direct physical contact, involving haptic sensing and kinesthesia. **(B)** Distal sensorimotor coupling based on distance senses including vision and audition to feed action-perception loops. Modified from (Hasson et al., 2012).

can be concurrently recorded from two or more subjects (see section on ‚Extrinsic neural coupling modes' below).

In summary, we suggest the notion of coupling with varying levels of complexity (check, sync and unite SMCs) and an integrated perspective of intrinsic and extrinsic coupling modes to be particularly helpful to understand social behavior. A key prediction is that changes of social entrainment, i.e., proximal or distal sensorimotor coupling, should be associated with changes in social engagement, which may be quantified by subjective ratings of the interaction quality or the degree of cooperation. Thus, we expect that a modulation of basic coupling modes, in particular at the level of sync SMCs and unite SMCs, should lead to changes in presumed high-level social cognitive phenomena, such as mutual trust or empathy (Froese et al., 2014; Keller et al., 2014; Llobera et al., 2016). To achieve such a modulation, entrainment through shared perceptual and sensorimotor rhythms is likely to be an important mechanism. Conversely, fluctuations in social engagement might also lead to a differently organized dynamics of intrinsic and extrinsic coupling processes. Thus, for instance, the dynamics of sensorimotor coordination of two individuals should be influenced by social-cognitive factors such as, e.g., shared intentionalty or joint attention. Furthermore, the socSMCs concept emphasizes the continuity between low-level SMCs, which directly involve sensory and motor areas, as well as basal ganglia and cerebellum, and socially deployed action-effect contingencies. Thus, we hypothesize that there may be a strong overlap regarding the brain networks involved in both the former and the latter, as well as an interaction between the intrinsic and extrinsic coupling modes subserving the different types of SMCs. Moreover, with its focus on shared perceptual and sensorimotor rhythms as a core part of the architecture of social cognition, the socSMCs concept also leads to the hypothesis that disturbances of these coupling modes may contribute to clinical deficits in social cognition, and that interventions at this level may provide an important tool to promote well-being at an interpersonal level.

**Relation to other concepts of social interaction**

According to the socSMCs concept, social interaction strongly depends on dynamic coupling between agents and their environment, hence a deeper understanding of this interaction dynamics promises to provide important insights into social cognition. Our view shares aspects with the interactionist concept of social cognition (Di Paolo and De Jaegher, 2012; Di Paolo et al., 2018; De Jaegher, 2021) which proposes an extension of the enactivist position to social and affective domains, emphasising that sense-making occurs in a participatory manner and that central aspects of cognition are inherently relational (De Jaegher and Di Paolo, 2007; De Jaegher et al., 2010; see also Durt et al., 2017). The proponents of this enactive view of social cognition emphasize the relevance of self-other contingencies for the coordination between agents in the interaction process (McGann and De Jaegher, 2009). However, a difference to the socSMCs concept is that a relation between social entrainment and intrinsic dynamics of the agents, in particular intrinsic neural coupling modes, is not considered. Furthermore, our concept agrees well with the joint action model by Knoblich and Sebanz (2008), which creates a close link between shared intentionality and joint action, based on the consideration of scenarios with different levels of complexity and flexibility of social interaction. However, the aspect of dynamic coupling is not considered in this model which, rather, focuses on the representation of perceived action in the agents (Sebanz et al., 2006; Knoblich and Sebanz, 2008).

Relations also exist to the concept of ‚coordination dynamics', which originated from earlier ideas on self-organising pattern formation (Tognoli and Kelso, 2014; Tognoli et al., 2020). Coordination dynamics applies dynamical systems theory to biological networks, suggesting that a system is best described by looking at the coupling of its parts via mutual information exchange. An important distinction at the heart of this dynamical view is between (1) coupling of system components with similar dynamics, leading to formation of attractors or multistability; and (2) coupling of system parts with dissimilar dynamics, which prevents phase-locking and leads to metastability, i.e., integrative and segregative tendencies alternate in the interaction dynamics. Kelso and coworkers have suggested that these two modes of coupling (multistable vs. metastable) might be useful to describe social coordination. Metastability is particularly interesting also because it represents a state of collective dynamics where new information can be created (Tognoli and Kelso 2014). The application of this concept to the case of social interaction has been shown to provide very useful tools for the analysis of the interaction dynamics, such as coupled oscillator models (Tognoli et al., 2020). Yet, the focus of this approach has so far been on behavioral aspects of the coordination dynamics and not primarily on the explanation of social cognition and social perception.

Of note, the socSMCs concept differs from classical concepts in social neuroscience. A major focus of work on the neural foundations of social cognition has, in the past decades, been on the capacity of the brain to mirror the actions of others, thus enabling the simulation and representation of other agents' mental states (Gallese and Goldman, 1998). One of the highly interesting aspects of this approach is its strong emphasis on the role of motor and premotor systems in social cognition. Neuroimaging studies have identified brain areas and networks that are activated during tasks involving mentalizing, empathy or mirroring (Stanley and Adolphs, 2013). A relation between motor control and social cognition is also suggested by work on motor mimicry, an unconscious and spontaneous form of interpersonal coordination, which is likely mediated by the mirror neuron system (Wang and Hamilton, 2012). Along the same lines, De Waal and Preston have proposed a perception-action model of empathy, which postulates the emergence of empathy from basic sensorimotor processes and overlapping representations for performing and observing actions (De Waal and Preston, 2017). Several approaches have suggested a key role for predictive mechanisms in social cognition and also have explored their relevance for disturbed social processing (Blakemore and Decety, 2001; Brown and Brüne, 2012; Sinha et al., 2014). Sokolov and coworkers have highlighted the potential relevance of cerebellar circuits for signalling of prediction errors in social context (Sokolov et al., 2017; Sokolov, 2018). In contrast to the majority of the concepts that have been developed in social neuroscience so far, the socSMCs concept focuses on low-level sensorimotor interactions leading to social entrainment and engagement and, vice versa, the influence of social context on the development of basic sensorimotor relations. Pezzulo and colleagues emphasize the role of sensorimotor communication in social interaction scenarios of different complexity but without any link to the concept of sensorimotor contingencies (Pezzulo et al., 2019). Hasson and coworkers have proposed that social interactions involve the informational coupling of the perceptual system of one brain to the motor system of another which can lead to behavioral alignment, e.g., in verbal communication (Hasson et al., 2012; Hasson and Frith, 2016). However, these authors do not explicitly consider the link between such an extrinsic coupling to intrinsic coupling modes.

The socSMCs concept also differs from classical concepts in social cognition research, in particular, from theory of mind-based approaches. The concept of a theory of mind refers to the idea that a person is aware of the existence of their own subjective experience of the world, and the difference to that of another person. As such, research into this direction describes and promotes social interaction as mediated by theory-theory or simulation-theory (Carruthers and Smith, 1996; Gallese and Goldman, 1998), both of which invoke a meta-level of social cognition, and a distancing from the ongoing moment-to-moment interaction with other agents. In contrast, the socSMCs concept emphasizes the role of more basic or immediate processes of social sense-making, seeking to explain how abstract or higher level insights and decisions come about and are informed by bodily, dynamic and situational factors. This notion also aligns well with evidence from developmental research, suggesting that early in development, the social interaction modes emphasized in the socSMCs concept have primacy and are required to ground other, more explicit modes of social cognition (Campos et al., 2000; Di Paolo and De Jaegher, 2012). Rather than foregrounding models that we hold about others and our interactions with them, the socSMCs concept promotes a picture in which agents co-create shared effects in the world and, thus, understand sociality through the experience of enacting ‚we-modes' (Varela et al., 1991; De Jaegher and Di Paolo, 2007; De Jaegher et al., 2017). It should be noted that both ways of knowing matter: cognitive model-based prediction and dynamic social coupling, both involve habitual as well as creative components, mutually influence one another and contribute to our flexible engagement with the world (see also Pezzulo et al., 2019). Nonetheless, given the frequent lack of intra- and interpersonal sensorimotor, and experientially lived aspects of cognition in representational approaches, the socSMCs concept is an invitation to keep abstract reasoning and embodied relating at par, acknowledging that the two ways of understanding rely on each other.

### Social coordination dynamics

A major implication of the socSMCs concept is a shift in terms of what should be considered as core mechanisms of social cognition. How do we come to understand each other, work on a task together, or settle a dispute? According to the concept advocated here, for multiple agents to act together and understand one another, they must first and foremost find a way to coordinate their sensorimotor engagement with the world and with one another.

The importance of sensorimotor coordination for joint action is particularly evident in behaviors involving shared rhythms such as the applause of an audience which can occur in spontaneously emerging synchrony across many individuals. The dynamics of social coordination has been studied, for example, during rhythmic finger movements carried out by dyads of participants with and without visual feedback regarding their own and the other's movements (Oullier et al., 2008) (Figure C2.3). In epochs with visual feedback, phase synchrony emerged spontaneously between the finger movements, although the participants had not received any particular instruction about how to relate to the partner's finger movements. Of note, the effect of social entrainment persisted after periods of phase synchronization when visual feedback was eliminated by closing the eyes (Figure C2.3). This study provides a typical example for what we have termed sync SMCs above (Figure C2.1). The authors conclude that general features of coordination dynamics, such as multistability and phase transitions, which are observed in a broad variety of self-organizing dynamical systems, are also highly relevant in social interaction. These conclusions are also supported by recent work on joint rushing, i.e., the unconscious increase in pace that can occur during synchronized rhythmic activities (Wolf et al., 2019).

Further prime examples for social entrainment are provided by the coordination dynamics among musicians during ensemble performance (reviewed by Keller et al., 2014). In contrast to more basic laboratory paradigms, entrainment in musical ensembles requires coordination of complex movement sequences with variable temporal patterning. It has been suggested that several cognitive and sensorimotor capacities are required for successful social coupling in such complex settings, including (i) temporal adaptation, supported by mechanisms such as phase correction and period correction; (ii) attention to both the results of own actions, actions of the partners and the joint ensemble output; and (iii) anticipation of action outcomes based on highly precise temporal prediction capabilities (van der Steen and Keller, 2013; Keller et al., 2014). These studies in musical ensembles provide evidence for an impact of sensorimotor coordination on social cohesion, cooperation and trust and, overall, they provide a highly relevant case where synchronous group entrainment can enhance social affiliation (D'Ausilio et al., 2015). Similar conclusions have been reached in the study of musical improvisation involving duets or larger ensembles (Walton et al., 2018). Seeking to understand how musicians communicate and engage socially in an under-determined performance context, Walton and colleagues ascribe a central role to shared temporal structure that provides the foundation for performers to interpret and respond to the acts of their partners. Such shared rhythms may provide the basis for what we have termed unite SMCs and for more complex forms of social expression.

It should be emphasized that coordination dynamics is, of course, also relevant in non-rhythmic behaviors. Joint attention may serve as an example here (Sebanz et al., 2006). Joint attention is an important feature of social interaction, consisting in the capability of two or more agents to simultaneously direct their attention towards the same object. The capacity for engaging in joint attention is frequently taken to indicate the presence of theory of mind in the participating agents. However, the prominence of sensorimotor components in establishing and sustaining episodes of joint attention, e.g., eye and head movements, pointing and vocalizations, suggests that the concept of socSMCs may be well-placed to account for important parts of joint attention without the need to invoke theory of mind abilities (Maye et al., 2017). For example, exchanging looks or

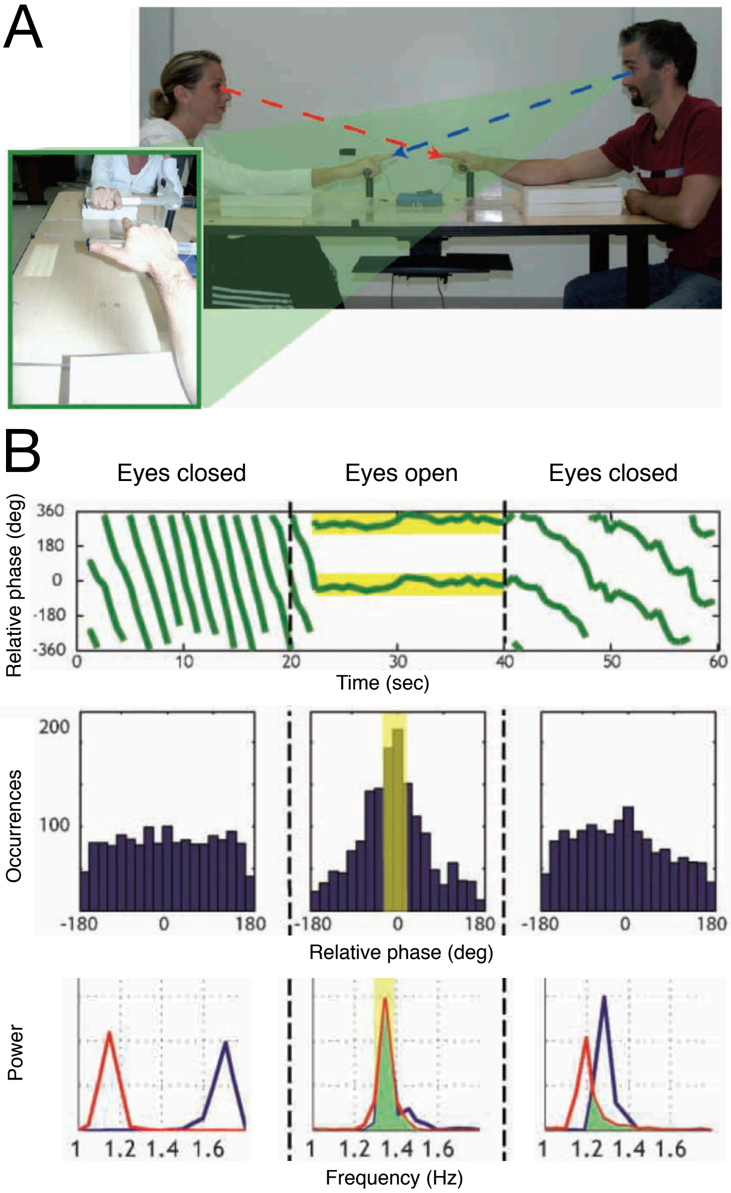


**Figure C2.3:** Coordination dynamics in social interaction. **(A)** Experimental setup. Participants were seated opposite to each other and instructed to move their index finger up and down continuously, either with eyes open or eyes closed in separate periods. Importantly, no specific instructions about the coordination of the finger movements were given. **(B)** **(Top)** Relative phase of the finger movements, indicating synchrony when participants had their eyes open and were viewing each other's movements. **(Middle)** Occurrence of relative phase lags of movements. With eyes open, zero phase lag dominated the distribution. **(Bottom)** With eyes open, participants adopted the same movement frequency; of note, movement frequencies remained similar when participants closed their eyes again. Modified from (Oullier et al., 2008).

alternating gaze direction between the partner and the object of interest is a simple but powerful mechanism that can establish the mutual awareness of being jointly engaged in a perceptual episode. In addition to gaze perception, also head or body orientation may be used to infer the target of attention. This view receives support from behavioral studies in humans showing that providing the partners with information about each other's gaze can significantly improve performance in a collaborative search task (Wahn et al., 2015). The socSMCs concept refutes the necessity of explicitly detecting and representing the state of somebody else's attention. Rather, it highlights the efficacy of the co-attender in modulating the interaction between both individuals and between them and the attended object. This transforms the problem of detecting a state into one of establishing a coupling. Jointly attending agents are then organized through this coupling, offering them opportunity windows of coordinated engagement (Fantasia et al., 2014). Common foci of attention are not just passively shared; rather, the co-attenders also shape them, extend them over time by embedding them in task structures and conventionalize them in terms of canonical forms in the culture (Bruner, 1995).

Similar conclusions are suggested by developmental studies on joint attention. Humans engage in reciprocal attention from as early on as their first hour of life (Trevarthen, 2005; Reddy, 2008; Reddy and Uithol, 2016). Studying vocalizations, movement and gaze of infants interacting with their caregivers, key findings from this field of research include that infants easily follow others' gaze with their own (Hood et al., 1998; Moore and Corkum, 1998), respond meaningfully even to actions they themselves cannot produce (i.e., their capacities go beyond spectatorial mirroring) and joyfully enter into mutual responding with others, with whom they co-create rhythms and narratives. These developmental steps provide examples for the acquisition of what we term check SMCs and sync SMCs (Figure C2.1). We grow up in a field of social relations that offer opportunities to participate in joint attention settings, leading us to acquire a know-how about others as bearers of intentions (Reddy, 2003; De Jaegher et al., 2010). Thus, joint attention may be seen as an example for how sensorimotor coupling can lead to an alignment of the agents at the perceptual-motor level as a basic mechanism for mental alignment in joint action. This may be a seen as preparatory stage for the development of the capability to implicitly take another's perspective in cooperative situations and later to explicitly understand the other's perspective as such (Fuchs, 2013). We argue, furthermore, that such basic sensorimotor coordination dynamics influences, adapts and supports our more abstract ability to predict, read and engage with other's behavior and experience.

Indeed, one of the questions emerging from the socSMC concept is whether subjective feelings of social engagement are associated with motion synchronization between agents, i.e., whether the degree of social engagement can be predicted by the strength of social entrainment. To study this hypothesis one can imagine several scenarios, e.g., situations in which agents synchronize their movements, act together to achieve common goals, play music, or dance together. One study investigating this influence used a three-dimensional mirror game, in which agents had to synchronize their movements (Llobera et al., 2016). Either one of the agents was leading or following, or they jointly improvised without a designated leader and follower. The analysis of motion data and of subjective ratings revealed that the perceived sensation of synchrony could be predicted by parameters of motor synchronization in this mirror game. Especially the speed differences between the agents' movements were a good predictor for the subjective sensation of synchrony.

Several studies also used objective measures to quantify social engagement, e.g., by the duration of co-confident motion which corresponds to jitter-free, synchronous movements of two interacting agents. Co-confident motion was first described in the mirror-game, a simple joint improvisation task (Noy et al., 2011; Hart et al., 2014; Gueugnon et al., 2016). Here, periods of co-confident motion were associated with increased social engagement and, thus, considered to indicate moments of togetherness. Even physiological parameters such as increased heart rates were shown to be associated with periods of co-confident motion and, moreover, these periods showed correlated heart rates between two improvising agents (Noy et al., 2015). We have recently obtained similar evidence in a joint attention task, in which two agents had to cooperate to determine the motion direction of a visual object on a screen. We observed that autonomic parameters related to heart rate variability could reflect the subjective evaluation of performance in the task (Maye et al., 2020). In other studies, personality traits such as the attachment style

(Bowlby, 1969) were used to predict complexity and synchronization of motion in joint improvisation (Feniger-Schaal et al., 2016, 2018).

**Impaired social coupling**

The concept advocated here also has implications for understanding the basis of social cognition disorders. Impaired communication plays a role in many areas of psychiatric and psychotherapeutic practice, from temporary cases of miscommunication to persistent deviations and impaired social interactions. Communication deficits are a highly relevant aspect in diverse psychiatric disorders, such as schizophrenia and other psychotic disorders (Baltaxe et al., 1995, Fioravanti et al., 2005), depression (Pope et al., 1970) and, in particular, neurodevelopmental disorders of the autism spectrum type (Magiati et al., 2014; Tillmann et al., 2019). The socSMCs concept predicts that patients with social cognitive deficits may suffer from deficits in mechanisms for interpersonal sensorimotor entrainment.

Autism spectrum disorder (ASD) may serve as a specific example for a condition with verbal as well as non-verbal communicative deviations (Lai et al., 2014). First described several decades ago in the context of schizophrenia as autistic thinking (Bleuler, 1911), autism was later investigated by Kanner (1943) and Asperger (1943) and underwent a considerable paradigm shift with the introduction of the autism spectrum (American Psychiatric Association, DSM V). Recently, ASD has been investigated extensively in the fields of psychology, psychiatry as well as clinical neuroscience (Frith and Frith, 2008; Happé and Frith, 2008; Wolfers et al., 2019). With symptoms that range from social and communicative to sensory and motor impairments, ASD's aetiology and pathophysiology are still not fully understood and until today, only very few established treatment options exist.

It has been argued that reduced social entrainment in ASD may relate to impaired perception of affordances provided by other persons' behaviors (Hellendorn, 2014). The Gibsonian notion that behavior affords behavior (Gibson, 1986) resonates well with the socSMCs concept proposed here, since it emphasizes the emergence of affordances in joint action and implies a coupling of perception-action loops supporting the social interaction (Hellendorn, 2014). An immediate application of socSMCs principles to ASD suggests strategies for enhancing social coupling at the sensorimotor level. Brezis and colleagues (2017), for example, compared autistic and typically developing participants' behavior on the mirror game, an open-ended task where two players take turns leading, following, and jointly improvising motion using two handles set on parallel tracks. They found that autistic participants had lower rates and shorter duration of co-confident motion, in particular when they were following. These differences remained even when controlling for motor skills. Based on participants' subjective reports, the authors suggest attention, motivation, and reward-processing as potential mediating factors, and propose to examine the potential of specific training of sensorimotor coordination to enhance patients' social cognitive abilities. Along these lines, a recent study has investigated the impact of a dance/movement intervention on social cognition in ASD (Koehne et al., 2016). The authors observed that training of movement imitation and synchronization increased emotion inference in adults with ASD.

Another well-studied domain of impaired SMCs in ASD are eye movements. Among the most frequently observed symptoms in ASD, the avoidance of eye contact leads to a range of consequences in social interaction. Studies on human social development show that 2-year old children with ASD tend to show significantly less visual fixation time on faces, when a video of an actress (acting as a care-giver) was presented (Jones et al., 2008), indicating a very early impairment in a social adaptive behavior that is regarded as evolutionarily vital for survival in humans and shown to be relevant for newborns at very early stages in development (Farroni et al., 2002). This early deficit seems to persist into adulthood, as shown in an eye-tracking study in adults using naturalistic social situations as stimuli (Klin et al., 2002). Importantly, this deficit also causes a lack of active perception in a critical time window in early development, in which basic learning processes drive social and emotional development, and may therefore be closely related to symptoms such as the difficulty to recognise emotional expressions in others (Eack et al., 2015). This difficulty is detrimental to any kind of communication and reported frequently in ASD as one of the most impairing symptoms. The case of gaze aversion exemplifies how active visual perception is intricately linked to both development and learning in social contexts as well as the successful unfolding of communicative acts.

Complementing these behavioral studies, neurophysiological evidence indicates that not only sensory (Robertson and Baron-Cohen, 2017) and motor (LeBarton and Landa, 2019) processing appears deviant in ASD, but also the interplay between these domains. It has been shown in children with ASD that resting state fMRI connectivity is reduced between visual and motor systems (Nebel et al., 2016). The reduction of visual-motor coupling was associated with symptom severity in terms of more severe social deficits. The socSMCs concept implies that social entrainment involves mechanisms for acquiring action-effect contingencies in the social interaction and, thus, a critical role of brain regions involved in prediction of sensory inputs and action outcomes, such as prefrontal cortex, premotor cortex, cingulate cortex, superior and middle temporal gyrus, basal ganglia and the cerebellum (Schubotz, 2007; Brown and Brüne, 2012; van der Steen and Keller, 2013; Sokolov, 2018; van Overwalle et al., 2019). Accordingly, deficits in such predictive mechanisms should have an impact on social entrainment. Indeed, a key deficit in ASD seems to concern the ability to form flexible predictions, leading to an impairment in processing of new or unexpected sensory inputs (Gomot and Wicker, 2012) and aberrant movement planning in joint action contexts (Gonzalez et al., 2013). Deficits in predictive mechanisms in ASD have also been postulated by Sinha and coworkers (2014). According to their proposal, an underlying deficit in predictive abilities may account for many of the salient traits in ASD, including sensory hypersensitivities, difficulties to interact with dynamic objects, reduced motor anticipation, as well as difficulties in anticipating the actions of other persons (Sinha et al., 2014). At the neural level, this predictive impairment may relate to alterations in structures involved in prediction like the basal ganglia, anterior cingulate and cerebellum (Sinha et al., 2014; Sokolov et al., 2017; Sokolov, 2018; van Overwalle et al., 2019). In particular, the cerebellum shows developmental alterations in ASD, including strong expression of ASD susceptability genes, volume decreases and cellular abnormalities (Wang et al., 2014). This agrees with a role of cerebellar circuits in outcome prediction, signaling of prediction errors and perception of a person's motion and body language in social context (Sokolov et al., 2017; Sokolov, 2018; van Overwalle et al., 2019). Deficits in sensorimotor entrainment in ASD have been examined by Hamilton and coworkers, who studied motor mimicry in social interaction (Wang and Hamilton, 2012; Forbes et al., 2017). They observed that people with ASD can still mimic, i.e., unconsciously copy the actions of others, but do not use social cues like, e.g., gaze to control what to mimic (Forbes et al., 2017). This provides support for the hypothesis proposed here, demonstrating mimicry as a socially relevant coupling mode which influences engagement through sensorimotor entrainment.

**Extrinsic neural coupling modes**

To explore the neural mechanisms involved in social interaction, the concurrent observation of brain dynamics ongoing in two (or more) people who communicate, work on a joint task, or improvise together seems highly informative. In recent years, the investigation of inter-brain coupling using so-called hyperscanning methods based on simultaneous electro- or magnetoencephalographic (EEG/MEG) recordings or functional magnetic imaging (fMRI) scans of individuals engaged in a social task has gained attention in social neuroscience (Montague et al., 2002; Schippers et al., 2010; Hasson et al., 2012; Sänger et al., 2013; for a recent review also see Czeszumski et al., 2020). These approaches investigate the neural signatures of dynamic social coordination, the temporal and spatial scales on which brains interact and the correlates of behavioral coordination at the level of brain-to-brain coupling. Hyperscanning paradigms employed to investigate social interactions are manifold, including joint musical performance (Lindenberger et al., 2009; Sänger et al., 2013; Novembre et al., 2016), verbal communication (Liu et al., 2017; Li et al., 2021), decision-making in economic games (King-Casas et al., 2005; Krueger et al., 2007; Jahng et al., 2017; Hu et al., 2018), and sensorimotor coordination and imitation (Hari and Kujala, 2009; Babiloni and Astolfi, 2014; Hari et al., 2015; Liu et al., 2018; Nummenmaa et al., 2018). The intriguing idea of investigating social interactions by simultaneously recording neuronal activity from interacting brains has also been implemented for the investigation of adult-infant interactions (Hasegawa et al., 2016; Leong et al., 2017), pain perception and interpersonal touch (Goldstein et al., 2018), and has been transferred to real-life scenarios such as flight simulations in professional pilots (Toppi et al., 2016) and classroom group dynamics (Dikker et al., 2017).

To identify neural signatures of social interactions, connectivity analyses have been applied to measure both phase as well as envelope brain-to-brain coupling. The quantification of inter-brain coupling in EEG and MEG hyperscanning data includes the assessment of phase-locking between oscillatory activity in specific frequency bands (Lindenberger et al., 2009; Dumas et al., 2010, Sänger et al., 2013), as well as amplitude envelope correlations of oscillatory power (Tognoli et al., 2007; Naeem et al., 2012; Kawasaki et al., 2013). There is growing evidence from EEG/MEG hyperscanning studies that links connectivity between brains to interpersonal coordination and joint action (see for example Dumas et al., 2010; Szymanski et al., 2016; Toppi et al., 2016; Kawasaki et al., 2018; Zamm et al., 2018). Particularly, in experimental paradigms involving

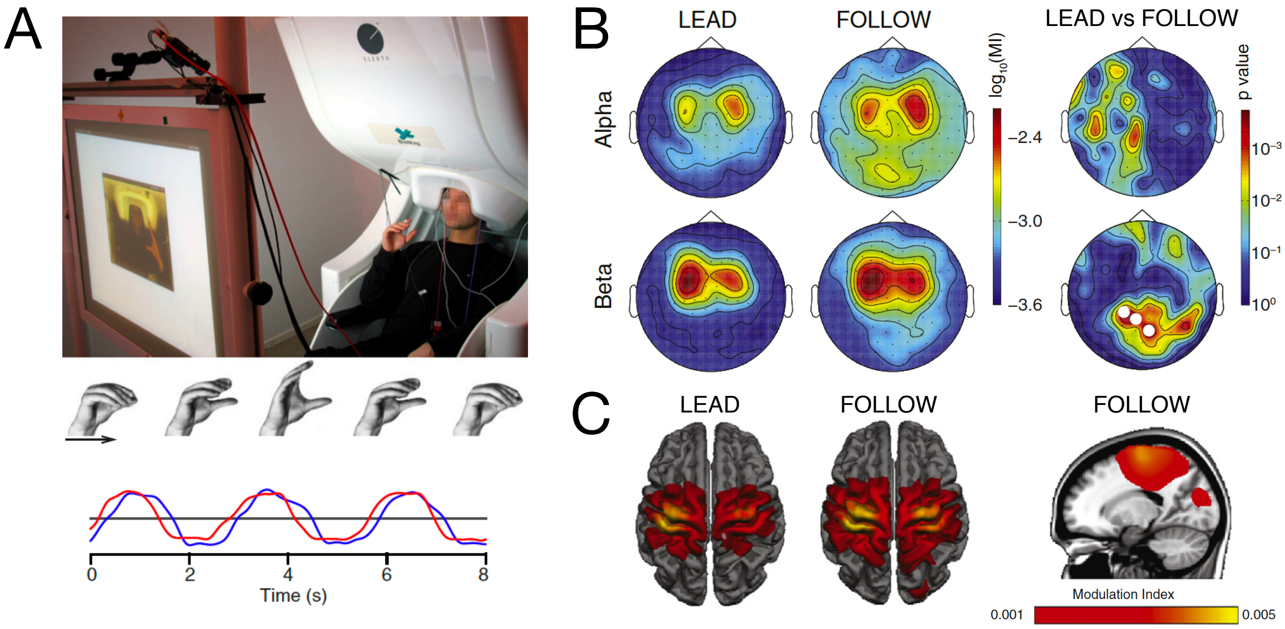


**Figure C2.4:** Modulation of brain signals by joint action. **(A)** Experimental setup. Participants were seated in two separate MEG systems and instructed to perform rhythmic precision-grip-like movements in synchrony with their partner, either leading or following the other's movement. Example movement traces (red, blue) are shown at the bottom, indicating similar movement with slight delay between the participants. **(B)** Modulation of alpha- and beta-band power by the phase of the hand movement in the two conditions. Modulations occurred over central areas and, for beta power, also over visual cortex. Significant differences between the leader and follower conditions (right) occurred only for beta-band power recorded from visual areas. This role-specific modulation of brain activity might be reflecting the need for the follower to coordinate own proprioceptive signals with the visual feedback about the movement of the leading participant. **(C)** Source space projection of the results shown in B. Power modulations are observed in sensorimotor cortex as well as, in the follower condition, in visual cortex. Modified from (Zhou et al., 2016).

rhythmic, musical or motor coordination, the alpha- (or mu rhythm, oscillatory activity ranging from 8-13 Hz) and beta- (15-30 Hz) bands seem to mediate inter-brain coupling (Tognoli et al; 2007; Lindenberger et al., 2009; Dumas et al., 2010; Naemm et al., 2012; Novembre et al., 2016; Kawasaki et al., 2018). Besides phase relations, amplitude envelope correlations between brains are computed to investigate slower fluctuations during coordinated behavior (Hari et al., 2015; Zamm et al., 2018), which may be more appropriate considering the timescale of interpersonal sensorimotor coordination.

The socSMCs concept suggests that establishing direct links between movement kinematics and neural data recorded during social interaction might be particularly promising. One way to link neural measurements with movement data in joint action research is exemplified by the work of Zhou and colleagues (2016). The authors used phase-amplitude coupling to quantify the relation between the phase of hand movement accelerations and oscillatory power in the alpha- and beta-bands during a joint motor task in a dual-MEG setup (Figure C2.4). The participants had to coordinate rhythmic precision-grip-like movements while brain signals were recorded simultaneously using two MEG systems. The goal of the task was to synchronize the own movements with that of the partner, either leading or following in the interaction. The data show a movement-related modulation of alpha- and beta-band power in sensorimotor cortex and, furthermore, a modulation of beta-band power in visual cortex, which was stronger in the follower compared to the leader condition. The authors suggest that this modulation of oscillatory brain activity might a signature of the need for the follower to coordinate own proprioceptive signals with the visual information about the movement of the leading participant (Zhou et al., 2016).

Several questions regarding the interpretation of hyperscanning results arise: (i) What is the substrate or underlying mechanism of inter-brain coupling? (ii) How can inter-brain processes shape the experience and behavior of individuals in interaction? (iii) In how far is observation at the brain-to-brain level more informative than, for example, an investigation of interpersonal sensorimotor dynamics? Given that direct coupling between neuronal ensembles of two brains can be ruled out for the lack of neuroanatomical connection, shared or synchronized sensory inputs, and coordinated motor outputs, are potential candidates. In keeping with this idea, Dumas (2011) suggested that when individuals' perception and action are coordinated, for example in a joint task, inter-brain synchrony may reflect sharing of information via between-individual sensorimotor loops or channels (Hasson and Frith, 2016; Pezzulo et al., 2019). Akin the differentiation of check, sync and unite SMCs, processes favouring the emergence of inter-brain synchrony may be described as ranging from similar external sensory stimulation of both individuals (check), reciprocal interpersonal action (sync), and group behavior that is inspired by a common ground, be it affective, informational or sociocultural (unite). Taken together, available hyperscanning studies provide evidence that sensorimotor or informational coupling between agents can be associated with inter-brain coupling of neural signals, supporting predictions that arise from the socSMCs concept.

Both phase and amplitude coupling methods have been criticised for finding spurious coupling, or hyper-connectivity non-existent in the data (Burgess, 2013; Hari et al., 2015). For example, two neuronal ensembles oscillating at the same frequency show high phase-locking per definition, without necessarily influencing each other. Another criticism observes that the EEG of two individuals taking part in the same experimental protocol likely shows inter-brain synchrony (due to identical sensory stimulation or similar motor output) in spite of a complete absence of interaction (Hari et al., 2015; Burgess, 2013). Circular correlation coefficients, mutual information (Burgess, 2013), or canonical correlation analyses (Campi et al., 2013; Hari et al., 2015; Vidaurre et al., 2019) have been suggested as measures that may avoid such spurious coupling. In addition, comparing inter- brain coupling in real participant pairs with randomly selected pairs (e.g., Bilek et al., 2015; Toppi et al., 2016) might aid the identification of non-trivial synchronization effects linked to the interaction between agents. However, it remains a complex task to differentiate between the diverse communicative processes involved in social interaction and to then identify their respective substrates.

The socSMCs concept argues for an integrative analysis of interaction data, including behavioral coordination in terms of sensorimotor coupling between agents, inter-brain synchronization, and subjectively experienced social engagement. A testable hypothesis is the prediction of self-assessment of social engagement, as measured by questionnaires or rating scales administered during joint action, from measures of behavioral and neural coupling between agents. Supporting this hypothesis, several studies have linked neural synchronization between interacting brains to subjective experience, e.g., feelings of engagement and social closeness (e.g., Dikker et al., 2017) or ratings of pain experience (Goldstein et al., 2018). These findings are complemented by evidence linking movement synchronization to social cohesion and subjective experience (as detailed above and also reviewed in Valencia and Froese, 2020). From the viewpoint of socSMCs, it is desirable to now go a step further and combine measures of social entrainment and social engagement, i.e., sensorimotor coupling, inter-brain synchronization and subjective experience into one model of social interaction.

Hyperscanning setups have also been used for joint neuromodulation of interacting participants, using an interventional approach to further explore underlying mechanisms of inter-brain coupling. In a study involving transcranial alternating current stimulation (tACS) applied simultaneously over motor cortex in two subjects during a joint finger tapping task, movement synchrony was enhanced by in-phase beta-band tACS (Novembre et al., 2017). Another study used dual-brain tACS to augment social interactive learning by enhancing spontaneous movement synchrony (Pan et al., 2020). Future studies might test whether such neuromodulatory interventions that lead to enhanced movement synchrony also have a potential impact on the subjects' assessment of social engagement.

As discussed earlier, we propose that the socSMCs concept might also provide new angles for neuropsychiatric research and psychological treatment, for example in ASD. Several studies have investigated interpersonally shared sensorimotor rhythms and their role for joint attention, mutual trust or empathy in hyperscanning setups involving ASD patients. These studies have revealed reduced inter-brain coupling in dyads involving ASD participants compared to neurotypical controls, which was associated with the impairment of the social interaction and/or the severity of ASD (Tanabe et al., 2012; Salmi et al., 2013; Hasegawa et al., 2016).

**Relevance for human-robot interaction**

We propose that the relevance of sensorimotor entrainment for social coupling not only applies to human social interaction, but can also serve to improve human-robot interaction (HRI). In fact, work in robotics provides early implementations of decentralised embodied executive control (Brooks, 1991). In the development of socSMCs-based robot controllers, the focus lies on algorithms for learning and deploying action-effect contingencies rather than for extracting semantic features from the sensor data, high-level reasoning and action planning and execution as in current mainstream robotics. The socSMCs concept suggests that many of the social action-effect contingencies involved in HRI can be observed by using rather simple features calculated from the sensory data. For example, optical flow can be used to entrain a population of neuronal oscillators by adjusting their phases and frequencies. When a motor control signal is derived from a weighted superposition of the oscillator signals, this model enables a robot to imitate gestures and to synchronize its movements with the human partner (Ansermin et al., 2016). Exploiting the mutual entrainment drastically simplifies the computational complexity of gesture mirroring and achieves millisecond-precision synchronization, which is challenging to accomplish with controllers that require high-level planning processes. Other low-level sensor data, like, for example, from distance sensors, collision detectors or the power consumption of the wheel drive, have been used to learn associations between actions and resulting changes in the sensory input, i.e., SMCs. Basically, sensor readings were combined to form an entry into a memory of SMCs that the robot had explored in the corresponding context. A reward function was used to rank different behavioral options. Together with a history of recently activated SMCs, the robot could develop an understanding of the geometric properties of its environment (Maye and Engel, 2011). This allowed the robot to traverse the space without hitting obstacles not because it was programmed to pull back whenever a distance sensor flagged an imminent collision, but because it inferred from the learned SMCs and its previous action sequence where it was and that moving on would have a detrimental effect.

The reward structure of behavioral options that is conditioned on the recent history of sensorimotor interactions can be conveniently captured by Hidden Markov Models (Maye and Engel, 2013). A powerful feature of this approach is the dual use of the model. Employed as a forward model, imagined or observed sensorimotor sequences can be used to simulate future behavioral trajectories and gauge their outcomes. In the backward direction, histories of sensorimotor interaction can be searched for common patterns which effectively is a way to derive more abstract knowledge from a set of particular interactions that all yielded the same effect.

We hypothesize that implementing social interaction capabilities in a robot which already is driven by knowledge of relevant SMCs may not depend on any critical module or function, as little as social cognition does not require any extra components that a cognitive agent wouldn't have. Therefore, adapting SMC-based robotic approaches to the social level by including socially relevant, low-level sensorimotor features seems straightforward. A model case for this transition has been made in a study which investigated a scenario where a robot and a human jointly balanced a ball (Ghadirzadeh et al., 2016). At the first stage, the robot learned the own action-effect contingencies of tilting its end of the plank and the trajectory of the ball. It then collaborated with a human by optimizing the joint goal function which kept the ball on the plank. An example for a real-world scenario that strongly relies on this type of sensorimotor coupling is the joint lifting and carrying of heavy objects, e.g., during removal of furniture to a new home. Reinforcement learning was employed for action selection from learnt SMCs, and residual uncertainty of human actions was modeled by Gaussian processes. The possibility to predict human movements from chunks of past trajectories indicates that human behavior indeed exhibits patterns which can be exploited by robot controllers (Bütepage et al., 2018). Instead of top-down approaches like explicit cost functions or target-specific training data, the authors used a bottom-up, data-driven model that was trained in an unsupervised way. Knowing regularities in the way humans move allows the controller to make predictions about the human's actions, which greatly limits the space of possible robot movement trajectories and thereby lowers response times

(Bütepage et al., 2019). It has to be pointed out that this approach is different from gesture recognition in that it does not attempt to derive abstract descriptions of the movements like pointing or stirring, which is then the basis for decision making and action planning. In the socSMCs framework, the robot is rather controlled by a network of sensorimotor memory traces in which reward-based learning assigned utilities to paths and which can be used by the controller to evaluate behavioral options. More generally speaking, developing HRI on the basis of the socSMCs concept does not suggest to introduce articulated contingency detector modules. Social coordination, rather, results from linking the individual agents' networks of SMCs through the interaction, thus constituting a global network in which circular causality drives the collective dynamics. Corresponding simulation studies in evolutionary robotics have successfully modeled interaction dynamics in the perceptual crossing paradigm in which participants seek to differentiate a partner, their shadow and a static object - all of which feel the same as you cross them, only two of which move, and only one of which (the partner) responds to one's presence (Di Paolo et al., 2008).

By making human behavior more accessible for robot controllers, wearable sensors may help bridging the currently very different physical substrates of human and artificial agents and facilitate social entrainment in HRI. For example, data from a head-worn inertial measurement unit can enable a robot controller to learn human movement patterns related to mutual attentiveness, coordination and overall positivity (Hwang et al., 2019). We suggest that HRI feels natural to the extent that SMCs acquired in human-human interaction can be deployed also in the interaction with the robot. This idea has consequences for all aspects of robotic development. For example, synchronized movements, such as when we pass on or carry objects together, require mutual frequency adaptation in the human and the robot. This process runs much more efficient if the intrinsic frequency properties of the human and robotic embodiments are compatible (Ansermin et al., 2017), which can inform the mechanical design of robots, e.g., to size robotic limbs comparable to those of humans. Another effort to narrow the gap between different embodiments and make SMCs acquired in human-human interaction useful in the context of HRI may be the development of methods for endowing robots with facial expressions (Vouloutsi et al., 2019). This may be seen as a gimmick at first; however, from the socSMCs perspective, changing facial expressions support just another subset of SMCs that humans engage in their mutual interaction, which may facilitate also the interaction with the robot.

Thus, socSMCs-based human-robot coupling may enhance computational efficiency through information reduction and yield robot controllers that depend less on abstract explicit internal representations, rendering real-time control of the interaction feasible. A few iterations of the interpersonal sensorimotor loop may activate memories of previous or similar interactions which may then modulate the relative weighting of possible behavioral options that the agents can choose from. This also has the potential to replace rather discrete switching of the active role between the human and the robot with quasi-continuous turn-taking, encouraging the feeling of doing something together as opposed to interacting with a machine.

**Grounding togetherness in dynamic coordination**

As pointed out above, the socSMCs concept combines pragmatic (embodied, enactive) approaches with a constitutive role of social interaction, questioning the appropriateness of conceiving minds as independent individual entities (see also De Jaegher and Di Paolo, 2007; Gallagher, 2008; Kyselo, 2016; Satne and Roepstorff, 2015). For the study of human social capabilities, this implies a dissolution of the boundaries between me and the other that pervade classical cognitivist approaches. In particular, the socSMCs concept focuses on the relation between coupling dynamics at neurophysiological and behavioral levels, and the varying degrees of social engagement experienced by the individuals. This is in line with results from studies that used the mirror game, a simple setup in which two players sit opposite each other and coordinate the movement of two handles placed on parallel tracks in front of them. Noy and colleagues (2011) show that highly jitter-free, co-confident movement goes hand in hand with the highly agreeable experience of togetherness - a subjective merging of self and other, accompanied by the sense that every action is the right one. In a follow-up study, Noy and colleagues (2015) further showed how both subjective ratings of moving together and objective motion-based markers are predictive of physiological responses like correlated heart rate fluctuations.

The socSMCs concept also receives support from studies that highlight the role of active sensorimotor coordination for agent recognition in a simple virtual game involving perceptual crossing (Froese and Di Paolo, 2010; Auvray and Rohde, 2012; Froese et al., 2014; Lenay, 2017). In the experimental paradigm used by Auvray and Rohde (2012), two individuals move an avatar along a virtual line, on which they meet three kinds of objects: the avatar of the other player, the shadow of the other player, as well as a stationary object. While all objects feel the same (they produce a vibration) to the players, only one of them can feel and respond to co-presence: the other player's avatar. This alone suffices for players to reliably identify one another in the virtual space, based on players' ability to recognise mobile objects, as well as the fact that due to the interaction dynamic, they more frequently met their partner, versus their partner's shadow.

Another line of work that generates insight into how social engagement emerges through interaction is provided by studies of musical improvisation. For instance, Walton and colleagues (2018) used a combination of interviews and behavioral modelling to better understand the interactions between pairs of jazz pianists. Their models relate musicians' upper-body and musical movement (recordings of key-press timings and notes played) to changes in the musical environment (two different rhythmic background sounds), and the experience of successful and creative performance as inferred from analysis of the interviews. One of their main findings was that players' experience was heavily influenced by how well they were able to co-create a narrative - a structure to guide their collaborative play and the emergence of new behaviors. Importantly, the study demonstrates a clear relation between the movement coordination of the players and the subjective experience of social engagement, thus supporting one of the prediction of the socSMCs concept.

A closely related field of research is the study of dyadic or group improvisation in the form of dance (Himberg et al., 2018; Kimmel et al., 2018). Akin the joint creation and negotiation of time in music, Himberg and colleagues (2018) focus on movement coordination (quantified by motion capture) and first-person appraisal thereof (inferred from interviews and questionnaires) as a vehicle for the aesthetic experience of togetherness, i.e., moments in which dancers experience heightened connection among the group, and a genuinely distributed sense of agency. The authors establish felt togetherness as a cross-sensory and inherently shared phenomenon that clearly relates to the agents' coordination dynamics. Kimmel and colleagues (2018) provide a detailed phenomenological account, based on interview techniques, of how dancers co-create movement sequences in the explorative practice of contact improvisation. Constrained only by concerns for safety, collaboration and respect, dancers in contact improvisation deploy rolling, sliding and falling movements to solve and create interactive challenges with their partner and the ground.

That social cohesion and interpersonal movement coordination are related is also revealed in experimental evidence from psychotherapeutic settings. For example, Ramseyer and Tschacher (2014) analyzed video-recorded therapy sessions and showed that both the amount of movement in patient and therapist, as well as the degree to which these movements correlate, positively predict therapeutic outcome (see also Tschacher et al., 2017; Moulder et al., 2018).

Another vast line of support for the intricate relations between physical and personal or social dynamics comes from functional neuroanatomy. For example, the large body of work provided by Craig (2009a, 2009b) provides detailed accounts of the neurophysiological overlap of brain regions and pathways associated with monitoring of bodily states, with areas and pathways implicated in emotion, one's subjective experience of time, and other dimensions of social and self-awareness.

Together, these findings indicate that the skill to create and express oneself in coordinative structures in real-time, together with sensitivity to one's own bodily sensations, contributes critically to the phenomenon of togetherness in social interaction dynamics. These studies support the proposal that a shared space of SMCs underlies agents' experiences of an engaging social interaction, both in the sense of being safe and predictable, as well as inviting and stimulating.

**Conclusions**

As discussed above, the socSMCs concept places joint action center stage and highlights in particular the situated and embodied sensorimotor processes that facilitate our participation in a shared social world. Our proposal, thus, extends action-oriented accounts of cognition (Varela et al., 1991; Clark, 1997; Noë, 2004; Engel et al., 2013a) to the interaction between different cognitive systems and broadens, in particular, the notion of SMCs beyond their application in the theory of individual cognition (O'Regan and Noe, 2001). In providing an overview of existing approaches to account for the complexity of dynamics present in human social cognition, we have attempted to show that novel approaches and perspectives emerge from this view of social interaction. However, key questions also remain open and need further investigation. This concerns, for instance, the exact nature of the grounding of subjective experiences of social engagement in the jointly maintained situated sensorimotor dynamics, as well as the translation of this insight into novel frameworks and interventions to support social interaction in both everyday life and clinical settings.

Pursuing the idea that SMCs may be applied in the context of social cognition, the central notion of our proposal is to ground social interaction in modes of sensorimotor and informational coupling, shifting the focus of study onto investigations of coordination dynamics as a vehicle of social entrainment. Our proposal shares aspects with interactionist concepts and joint action models of social cognition, but the socSMCs concept puts an even stronger focus on the role of low-level sensorimotor interaction dynamics for social entrainment and engagement. As we have discussed, this shift in emphasis has potential implications for the understanding of mechanisms underlying social cognition in the healthy brain but also in conditions of impaired social capabilities such as ASD. While work on the neural foundations of social cognition has, in the past decades, strongly focused on the capacity of the brain to mirror the actions of others, recent work suggests a key role for predictive mechanisms in social cognition in health and disease, and dynamic coupling between agents has become an issue of increasing interest in social neuroscience. In the context of ASD, modulation of social understanding through sensorimotor entrainment may even provide a new approach for augmentation of social capabilities. In a long-term application-oriented perspective, the socSMCs concept may also give rise to novel strategies for human-robot interaction and cooperation and may allow to introduce new concepts for robotics in training of social skills, in ambient assisted living, and caregiving.

# CHAPTER 3: THE BALLGAME

This chapter presents work on the BallGame: a laboratory-based interactive coordination task used to generate multi-level records of engaged interaction dynamics. In the BallGame, two individuals coordinate their finger movements to steer a shared virtual ball around obstacles and towards as many targets as possible. Before, during and after the game, we collect data about their personality, experience, movement (of fingers and eyes) as well as brain activity[3]. The BallGame was developed and conducted entirely as part of the European socSMCs research consortium.

**Chapter 3A** presents an unpublished manuscript shortly before submission. It introduces the experimental task and protocol, and discusses mixed effects models to predict participants' experience ratings from parameters that capture their game concurrent behaviour and movement coordination, the interaction context and personality differences within the team. Additional analyses of variance (ANOVA) highlight changes over time and across joint play conditions.

Lübbert, A., Sengelmann, M., Schneider, T. R., Engel*, A. K. and Göschl*, F. Predicting social experience from dyadic interaction dynamics: the BallGame, a novel paradigm to study social cognition. *In preparation.*

Author contributions: AL and FG developed the experimental paradigm and analytic strategy in exchange with TS and AKE. MS, AL and FG implemented the hard- and software of the game environment and hyper scanning setup. AL and FG conducted the study and analysed the data. AL wrote the article in exchange with FG and TS.

**Chapter 3B** shows work in preparation. In particular, it summarises a thematic content analysis of individual interviews conducted with participants after the game. It further presents results from follow-up analyses based on findings from the interviews, concerning the influence of targets and obstacles on interpersonal movement coordination, within-trial changes across our levels of observation, and differences in the group of participants at the shift from joint to individual play.

Lübbert, A., Krause, H., Engel, A. K. and Göschl, F. The BallGame - In-depth Participant Reports and Follow-up Analyses. *In preparation*.

Author contributions: AL and FG developed the experimental paradigm in exchange with AKE. AL and HK developed the interview. AL conducted and analysed the interviews. AL and FG developed and implemented further analyses in exchange with AKE. AL wrote the article in exchange with FG.

**Appendix I** of this thesis provides supplementary materials to *Chapters 3A and 3B*, including a complete overview of statistics, visualisations of significant effects, the post-game interview and further details regarding both quantitative and qualitative analyses.

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[3] Eye-tracking data and EEG recordings are not included in the analyses presented in this thesis.

# CHAPTER 3A

## Predicting social experience from dyadic interaction dynamics: the BallGame, a novel paradigm to study social cognition

### Introduction: social cognition as multi-level relationality

When humans collaborate to solve a problem, a myriad of things happens. The environment shapes the language, movements and social roles we consider appropriate. The particularities of the task bring specific routines and skills to the foreground. How confident and well rested we are likewise influences our expectations, experience and behaviour.

The complex set of processes at the base of collaborative action has inspired a diverse audience of researchers. Here, we present an experimental design and analytic approach that serves the integration of several perspectives of research on social interaction. More specifically, we present a task that engages two participants in an interactive computer game, and perform analyses that interrelate their gaming behaviour, finger movement coordination, subjective experience and personality traits. At the heart of our approach is an interest in relationality: how do two players co-determine their interaction dynamic? How do different elements of this process, such as personality differences, the conditions of interaction, players' performance levels or their degree of movement coordination, relate?

Our approach is directly inspired by recent proposals to ground social cognition in interactive sensorimotor coordination (Lübbert et al, 2021). The concept of 'socialising sensorimotor contingencies' (ibid) highlights sensing and acting in mutual response as the key organising principle of social cognition. As such, it takes a pragmatic stance: it places social cognition in the relational domain between individuals, effectively describing social behaviour and experience as the consequence of dynamic cycles of informational and sensorimotor coupling between agents. To bring this perspective into the cognitive science laboratory, we here test whether changes in the experienced quality of interaction are associated with changes in sensorimotor coordination between interacting players. As reviewed by Lübbert and colleagues (2021), empirical studies from dance and music to classical cognitive science laboratory settings have linked movement synchronisation to neural synchronisation of interacting individuals (Dumas et al, 2010; Zhou et al, 2016), to their subjective experience (Llobera et al, 2016; Jakubowski et al, 2020; Ramseyer & Tschacher, 2016), as well as to contextual factors such as individual differences or task constraints (Feniger-Schaal et al, 2018; Vesper et al, 2016). However, studies that make room for interactive autonomy, generate detailed records through more than two channels of observation and bridge domains by integrating approaches and findings remain scarce. To contribute to their development, we present a framework that combines an engaging interactive task with multiple forms of qualitative and quantitative observation: the BallGame.

In the BallGame, two players coordinate their index finger movements to jointly steer a virtual ball towards targets and around obstacles. It offers participants possibilities for action that are overlapping (both players can steer the ball in any direction with equal maximal force), diverse (at any moment there are many possible ways forward) and stimulating (the game control and task are neither too easy nor too difficult, and present collaborative advantages). Interested in sensorimotor contingencies as a substrate of social cognition, we decided it was important to involve continuous movements instead of (discrete) button presses. We also chose a controller (and sensorimotor contingency) that is entirely unfamiliar to most people: steering a virtual ball by bending and flexing the index fingers. This allows participants to start at the same level of experience. Besides recording participants' finger movements and asking them to rate their experience in terms of their level of engagement, felt agreement with and predictability of their partner, we collected data about participants' personality, and gaming behaviour, and performed individual interviews at the end of the experiment[4].

As we designed the BallGame, we were particularly inspired by research with a highly reduced space for dyadic interaction: the perceptual crossing paradigm (Auvray & Rohde, 2012; Froese, Iizuka & Ikegami, 2014). In this setting, two players move an avatar across a digital line and receive a stimulus (e.g. a vibration on their finger tip) each time they encounter the other, the other's shadow or a stationary object. The resulting sensorimotor interaction dynamics leads players into stable interactions with one another, and allows them to reliably detect the other's presence. This finding convinced us to use a setup with continuous sensing and acting, and overlapping game control, trusting that players can identify their partner's actions and learn to coordinate. To stimulate interaction in the BallGame, we further decided to include invisible objects that may, however, be seen by one's partner. More specifically, we used two distinct joint play conditions in the BallGame: one in which players see exactly the same game landscape, and one in which they have complementary information about the locations of the obstacles - a condition that may challenge interpersonal coordination, but provides overall more information to the team. Beyond the parallel with natural social interactions (in which partners hold complementary perspectives and information about their situation), this design feature was inspired by Vesper and colleagues' (2016) finding about the important influence of shared perceptual information on how individuals coordinate to reach a joint goal. Comparing situations in which dyadic reaches are made with or without visual access to the reaching trajectory of the partner, the authors demonstrated that participants' actions become more pronounced (exaggerated) when they can see each other's actions, and less variable when they cannot.

By investigating individual experience as an interactive property - a characteristic of ongoing sensorimotor, interpersonal and situated relation - our design satisfies core ideas from current trends towards relationality in cognitive science, including '4EA' (embodied, enacted, extended, embedded and affective cognition, see e.g. Varela, Thompson & Rosch, 1991; Menary, 2010; Di

[4] We also collected eye-movement and EEG data but these data are not included in the present analysis.

Paolo, Rohde & De Jaegher, 2010; Newen, De Bruin & Gallagher, 2018; Candiotto & De Jaegher, 2021), as well as dynamic (Clark, 2016; Mojica & Froese, 2019; Konvalinka & Roepstorff, 2012), sensorimotor (O'Regan & Noë, 2001; Lübbert et al., 2021) and participatory (De Jaegher & Di Paolo, 2007; De Jaegher, 2007) approaches to the study of mind and life. These strands of research urge us to locate social cognition at interrelating and intersecting levels of organisation: from biological to cultural factors, in individuals, interacting parties as well as their environment. This implies that social cognitive processes (need space to) unfold across these levels, and that empirical investigation should consider dynamics across multiple levels of observation.

We find that our approach corresponds with this call. First, our participants needed to master a challenging game control (precise index finger movements) and had to coordinate their steering actions with their partner, both of which stimulate engagement and leave room for individual choice. We further assessed the impact of different periods of time (seconds, minutes, blocks of play), as well as shared versus complementary information between players (obstacle visibility) on the interaction dynamic. In our principal line of investigation, we then predicted participants' social experience from a combination of (multiple) operationalisations of interpersonal movement coordination, gaming behaviour, personality differences as well as the interaction context.

In line with the concept of social sensorimotor contingencies, the BallGame thus investigates social cognition as a process that establishes and details itself in embodied and situated interaction.

To summarise: the central research question that we pursue with the BallGame concerns the relationship between social experience and interpersonal sensorimotor coordination: is our experience of an interaction (in part) constituted by how well we coordinate our movements with our partner's? Can we thus predict participants' ratings of their experience of the interaction from their interpersonal finger movement coordination? Our second line of investigation concerns the evolution of participants' interaction over time and across conditions of joint play. In particular, we test for learning effects over trials and sessions of the game, and ask whether coordination is affected when participants have overall more but complementary information, compared to overall less but shared information.

## Methods

### Participants

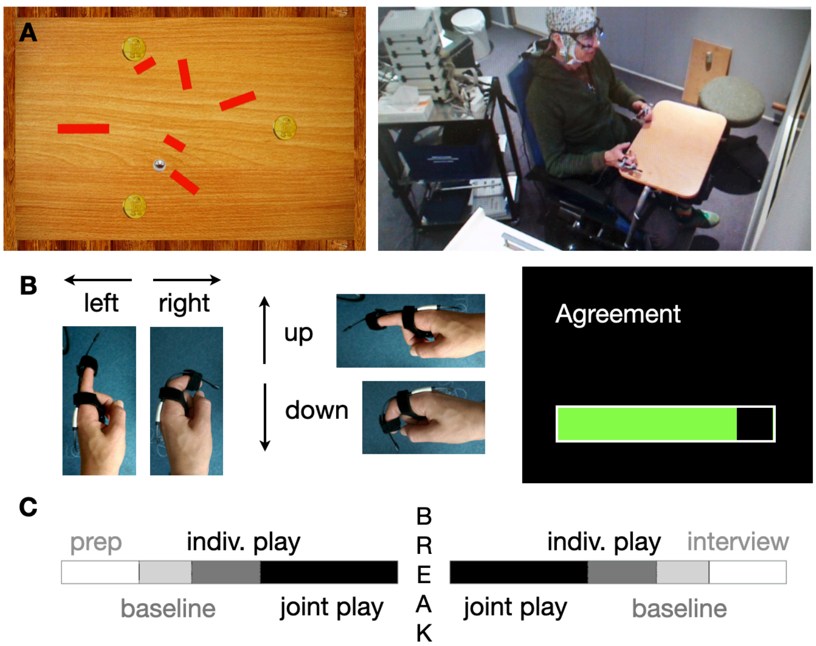
23 pairs of players (14 female-female pairs, 8 male-male pairs, 1 female-male pair; mean age 24.7 years, range 20-37) participated in the BallGame. Participants received monetary compensation for their time (10€ per hour), and a bonus depending on their success at the game (between 2.44€ and 6.96€). Participants had normal or corrected to normal vision and reported no history of neurological or psychiatric illness. The study was approved by the Ethics Committee of the Medical Association Hamburg (identifier PV5124) and conducted in accordance with the Declaration of Helsinki. Prior to the recordings, all participants provided written informed consent.

### The BallGame

The BallGame is a computer task in which two players use their index fingers to steer a ball across a two-dimensional surface, avoiding obstacles to collect as many targets as possible (*Figure C3A.1A, left* presents a screenshot of the game environment). Besides six visible obstacles, three additional obstacles remain invisible: players can learn about their location by keeping track of areas in which the ball suddenly slows down. The constellation of obstacles and targets shifts after each one-minute trial: the three outer targets (visible in *Figure C3A.1A, left*) rotate around the centre, and another 9 of 15 possible obstacle locations are activated (see *Figure C3A.1* for a more detailed description of this procedure). The goal is to get to know the landscape and collect as many targets as possible in limited time.

Throughout the game, participants continuously influence the movement of the ball, with their two index fingers controlling the acceleration of the ball along the x and y axes, respectively. When playing together, participants jointly determine the direction and speed of the ball: their acceleration is accumulated (up to a maximal speed), such that the ball quickly moves right when both players steer right, slowly to the right when players steer at orthogonal directions centred

**Figure C3A.1** Experimental Paradigm. **(A, left)** Screenshot of the game environment. Participants steer the ball (grey marble) to collect targets (golden coins) and avoid obstacles (red bars that slow down the ball to 10% of its speed). When the ball hits a target, the target disappears, and the currently inactive target becomes active/visible. After each one-minute trial, the location of targets and obstacles changes: targets are positioned at the centre and three equidistant points on a circle around the centre. The 9 obstacle locations (six visible, three invisible) are pseudo-randomly picked from 15 possible locations, so that all direct lines between the targets are blocked by at least one obstacle. The same 60 landscapes are used for all pairs (with the order of the landscapes shuffled within blocks). **(A, right)** View of a participant playing the BallGame, equipped with a 128-channel EEG cap, eye-tracker goggles and bimetal sensors attached to index fingers. **(B, left)** Demonstration of the game control - a bimetal sensor attached to the index finger translates bending and flexing of the finger into ball movement on the screen. **(B) right)** View of an example experience rating (bar filled by 'left-right' movement, answer confirmed with long 'down' movement). **(C)** Overview of the experimental protocol. After written and oral instructions, participants fill in questionnaires and are prepared for the game-concurrent data recording. The period at the computer begins with baseline tasks and a 10-trial block of individual play. After 40 trials of joint play (interrupted by a break in the middle of the session), participants complete another round of individual play and baseline tasks. The experiment ends with the individual interviews, during which the other participant waits or fills in the remaining personality questionnaires.



around rightward movement, and not at all, when players' steering directions are opposite. Over the course of the experiment, participants play the BallGame in three different conditions: individual play, joint play with the same obstacle visibility (SAME) and joint play with in part different obstacle visibility (DIFF; see *Figure C3A.2* for an illustration of the two joint play conditions). As such, the game presents collaborative advantages in the form of cumulative acceleration (though maximal ball speed is the same in joint and individual play) and complementary information (during joint play DIFF). Importantly, however, players also need to differentiate hitting an invisible obstacle from disagreeing with (steering in opposite directions to) their partner, which is particularly challenging during joint play DIFF, where there are more unilaterally (in)visible obstacles.

**Experimental protocol**

Both participants were scheduled to arrive at the institute at the same time. At their arrival, participants received written instructions to the game. As soon as both participants finished reading the instructions, the experimenter orally summarised the most important points and provided further information about the procedure and game environment. Importantly, participants were reminded of their collaborative advantage: in half of the joint-play trials (joint play 'DIFF' condition, see *Figure C3A.2A*), their partner could see the three obstacles that remained invisible to themselves. In this case, the team has more knowledge (of the obstacle locations) than each player individually. Participants neither know of the blocked trial-structure, nor which joint play condition they are currently playing. It was therefore advisable for them to always coordinate with their partner, that is to stay attentive towards their steering directions as potential signals about invisible obstacles.

After any remaining questions were clarified, participants took their seats in the two EEG chambers, situated in adjacent rooms. With a team of one to three assistants, the experimenter then prepared the game-concurrent data collection: participants were equipped with 128-channel passive electrode EEG caps (EASY CAP BC-128-x7-56, Herrsching, Germany) to record their brain activity, eye-tracker goggles (Pupil Core, Pupil Labs, Germany) to trace their pupil dilation and gaze-fixation, and bimetal sensors (Finger Twitch Transducer SS61L, BIOPAC Systems, USA) at both index fingers as game-control and to answer the questions about their experience of the game. The eye-tracker and bimetal sensors were then calibrated to fit individual movement ranges. After these preparations, we started the period at the computer. Participants first completed baseline tasks that are intended to serve as localisers for later EEG analyses (*note that the present work does not include analyses of the game concurrent EEG and eye tracking data*). Next, participants performed a 10-trial block of individual play to familiarise themselves with the BallGame, in particular the unusual game control: bending and flexing of their left and right index fingers to accelerate the ball along the x- and y-axes. We then proceeded with four 10-trial blocks of joint play, with the order of conditions (joint play SAME and DIFF) balanced over pairs. Afterwards, participants played alone again and completed another round of the baseline tasks. In the middle of the joint play period, we asked participants to take a break, during which they could

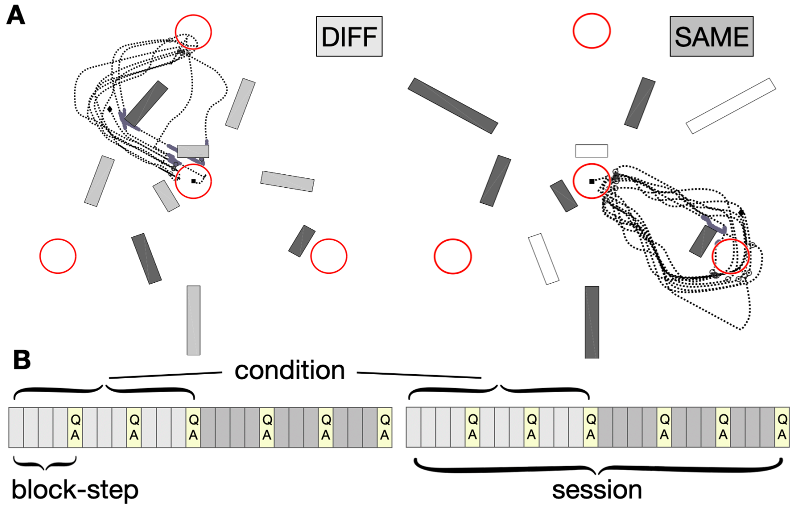



**Figure C3A.2** Joint Play Conditions. **(A)** Example trials of the two joint play conditions. In joint play DIFF, three of nine obstacles are visible to both players (dark grey bars), three only to player one and three only to player two (light grey bars). In joint play SAME, players see the same six of nine obstacles (dark grey bars) - three obstacles remain invisible to the team (empty bars). The black dotted line represents the path traveled by the ball in an example one-minute trial. **(B)** Experimental protocol of the joint play period. Participants play four 10-trial blocks structured in two sessions (with a break in between). In each session, participants play one block of each condition (SAME and DIFFerent obstacle visibility) and rate their experience in terms of their level of engagement, agreement and predictability (light-yellow bars with 'QA' label) at 12 time-points, in block steps of 4-3-3-trial intervals.

relax, use the bathroom, stretch or walk a bit. See *Figure C3A.1* for an overview of the experimental protocol and game environment.

During the play period, we informed participants about transitions between individual and joint play, and asked them to rate their experience concerning (a) Engagement: the level of involvement in or focus on the game, (b) Agreement: how much they felt to agree with actions taken by their partner, and (c) Predictability: the degree to which they understood or could predict their partner's behaviour. We invited participants to use these moments as small breaks - to close their eyes, relax hands and shoulders, drink water or eat a chocolate bar. *Figure C3A.2* presents example trials of the two joint play conditions, as well as a more detailed overview of the joint play period.

After their time at the computer, participants completed personality questionnaires. While they did so, we calculated their bonus payment based on the number of targets they collected. The experimenter further conducted a semi-structured interview with each participant about their experience of playing the game, while the other participant would continue filling in the questionnaires (see below, *Levels of Analysis*).

### Levels of observation

To capture the interaction dynamics at play in the BallGame, we organised our analysis along four *levels or channels of observation* with different *temporal resolution*: personality traits, experience, gaming behaviour and finger movement. Below, we describe how we measure and parametrise activity in each channel of observation - *Figure C3A.3* presents an overview of all parameters.

*Temporal resolution*: wherever possible (that is, for all measures except personality traits), we assess changes over time: across sessions (first vs. second half of the game), within a block of 10 trials à 60 seconds (splitting each block into three 'block steps' of 4, 3, and 3 trials) and within a trial (cutting each trial in three 20-second segments called 'trial steps'). There is a short break between the sessions, implying that participants indeed experience a first and a second part of the game. In case we cannot work with trial-level resolution, we aggregate data in block steps (see above): in parallel with the intervals at which we asked participants to rate their experience, we aggregate gaming behaviour and finger movement from the three or four trials that preceded a rating. Finally, the rationale for splitting each trial into three trial steps derives from our findings in the interviews: as outlined in more detail in *Chapter 3B*, players experienced the first part of the trial as more social compared to its later course, which motivated us to look for within-trial differences in our game-concurrent measures of observation.

*Personality traits*: participants filled in the NEO-FFI (Borkenau & Ostendorf, 2008), a general personality questionnaire that allows self-description along the dimensions of neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. They further completed the Autism Quotient (Baron-Cohen et al., 2001), and the SPF-IRI (Paulus, 2009), an interpersonal reactivity index that differentiates four subcomponents (perspective-taking, fantasy, empathic concern, and personal distress) which we aggregate (excluding the last factor) as our 'Empathy' measure.

*Experience ratings*: at fixed moments during the game - that is after trials 5, 10 (individual play); 14, 17, 20; 24, 27, 30; 34, 37, 40; 44, 47, 50 (joint play); 55 and 60 (individual play) - participants provided experience ratings. They did so by indicating their level of involvement in the game (**engagement** - throughout the entire play period), their felt degree of agreement or smooth performance as a team (**agreement** - only during joint play), and their ease of understanding and predicting the behaviour of their partner (**predictability** - only during joint play). Participants used the game control (the bimetal sensors attached to their index fingers) to provide their answers through a continuous slider. We translated their rating into integers from 0 to 100. After assessing the distributions of the rating data, we used the raw experience ratings for agreement and predictability ratings, but transformed the engagement ratings using the Arcsine transformation.

*Gaming behaviour*: we used four parameters to capture participants' gaming behaviour (see also *Figure C3A.3*) - generating one value per pair during the joint play, and separate values for each player during the individual play period. (1) **Number of targets collected***:* for each third of a trial, we counted the number of targets collected. (2) **Time spent on obstacle regions***:* for each third of a trial, we divided the number of frames the ball spent on any of the obstacles by the total number of frames. (3) **Total path length**: for each third of a trial, we integrated the path traveled by the ball. (4) **Target sequence complexity***:* for each trial, we evaluated how many times the ball went back and forth between two targets. That is, we counted target collection events that do not qualify as revisiting, and divided by the total number of targets collected in this trial. The resulting 'complexity index' ranges between 0 and 1, with lower values indicating lower tendency to vary the sequence (i.e., higher tendency to stick to an identified path and go back and forth between the same targets).

*Finger movement (basics)*: we calculated two basic movement properties. (1) **Distance**: to generate a simple, abstract measure that captures the amount of movement through which players control the game, we summed up the absolute velocity of the fingers (which control the x- and y-axis displacement of the ball in the game) for each third of a trial. (2) **Number of moves** (direction changes): to estimate the stability of steering, we counted how many times participants switched direction on the x- or y-axis in each third of a trial.

*Finger movement (coordination)*: to quantify the degree of coordination between participants' finger movements, we calculated seven parameters that assess either the relation between players' movements (undirected coordination), or potential leader-follower dynamics (directed coordination). All parameters are calculated based on participants' combined x- and y-axis movement, that is, the angle into which players steered the ball ('veering direction').

Our first set of measures is based on a *windowed lagged cross-correlation* (WLCC) analysis, in which we calculated the Spearman correlation between participants' veering direction over short windows of time. In line with Moulder and colleagues (2018), we generated five measures of coordination: we quantified (1) **synchrony** as the average WLCC coefficient across all lags (141 lags: maximal lag 1.1 seconds, single-frame resolution of 0.016 seconds at 60Hz), generating a series of synchrony values per trial (157 time steps for each one-minute trial: 0.3 second increments, 3.6 second time-windows), (2) **strength of relation** as the mean peak-picked

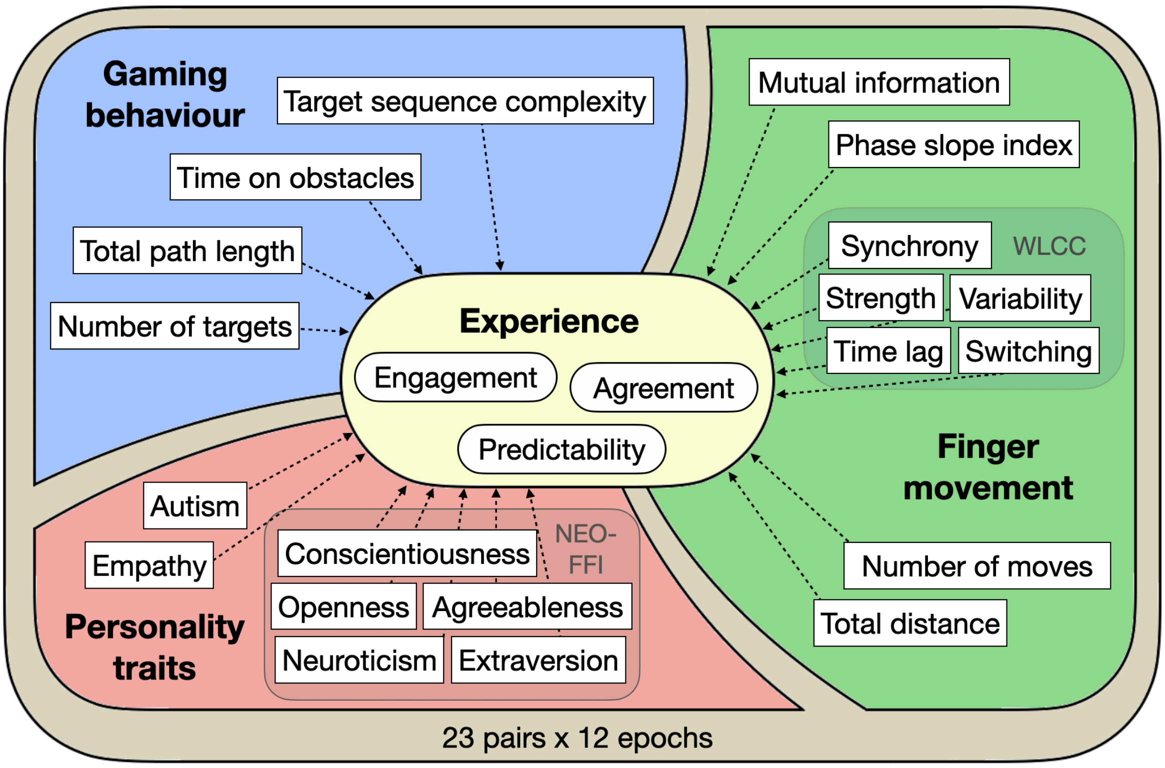



**Figure C3A.3** Levels (channels) and parameters of observation. We consider four channels of observations in the BallGame: personality traits (red), gaming behaviour (blue), finger movement (green) and experience (light-yellow). Each channel is described through a family of parameters. Within personality, we grouped the five traits indicated by the NEO five factor inventory (NEO-FFI). Within finger-movement, we grouped the five measures of windowed lagged cross-correlation (WLCC).

WLCC (ppWLCC) coefficient (the largest coefficient of correlation closest to a lag of zero), independent of the lag at which it was observed, (3) **variability of relation** as the standard deviation across ppWLCC coefficients, (4) **time lag** as the average absolute ppWLCC lag (ignoring which participant lead or lagged, showing only the relative time delay between players' veering directions). Finally, we assessed (5) **switching** behaviour as the standard deviation over ppWLCC lags.

We further quantified mutual information (**MI**) and calculated the phase slope index (**PSI**; Nolte et al., 2008) between players' veering directions. MI is a framework that allows for the quantification of shared information between two signals and is based on Shannon's entropy from information theory. Entropy is computed by binning the given data set, and calculating the probability of a given data point to fall into either of these bins. These probability values are then multiplied with the logarithm of the probabilities, summed and multiplied by minus one to return to a positive scale. MI is calculated by adding the individual entropies of the two signals and then subtracting their joint entropy (Cohen, 2014). PSI is a measure that quantifies the direction of information flow in multivariate time series. Formally, it corresponds to the weighted average of the slope of the phase of cross-spectra between two signals. In our case, these two signals are the veering directions of two players jointly steering a ball.

See *Appendix I, Supplementary Materials A*, for more methodological details.

**Statistical Analyses**

*Predicting experience ratings (linear mixed effects models)*: to test whether participants' experience ratings can be predicted from finger movement coordination while considering the influence of gaming behaviour and inter-personal differences, we calculated three linear mixed effects models (using R packages 'lme4', Bates et al, 2015, and 'lmerTest', Kuznetsova, Brockhoff & Christensen, 2017), one for each of our three types of experience rating (engagement, agreement and predictability - always taking the mean value of both players' answers). In parallel with participants' experience ratings, we aggregated all data into 12 epochs, yielding 276 observations per measure (23 pairs x 12 epochs). We initiated each model with the complete set of predictors provided through our three families of observation (4 measures of gaming behaviour, 9 measures of finger movement and 7 measures of personality difference), random intercepts for pairs, a trial-id parameter that continuously models the 12 epochs (4 x 3 block steps) of the joint play period, and an autoregressive covariance structure, modelling the dependence of repeated measures over time and allowing for greater similarity of observations that are closer in time (de Haan-Rietdijk, Kuppens & Hamaker, 2016). *Figure C3A.3* illustrates the initial model. We then used a restricted maximum-likelihood estimator to fit the model and iteratively eliminated the least significant predictor until only significant predictors were left. This backwards elimination procedure excluded the random intercept and the autoregressive covariance structure. We furthermore performed a leave-one-out cross-validation procedure to test the generalisability of our findings: we calculated a repeated measures correlation (using R package 'rmcorr', Bakdash & Marusich, 2021; see also, Bakdash & Marusich, 2017) between the actual (mean) ratings of our players, and the ratings we predicted based on model parameters that were fit to data from all but the present pair. Following the same rationale, we also calculated pair average correlations. In both cases, higher correlations between observed and predicted ratings speak to better generalisability of the model. Note, however, that this procedure only considers fixed effects.

*Variance over time and across game conditions (MANOVAs and ANOVAs)*: to test for general trends in our three families of game-concurrent observations (experience, gaming behaviour, and finger movement), we calculated multivariate repeated measures analyses of variances (MANOVAs) (using the R package 'MANOVA.RM', Friedrich, Konietschke & Pauly, 2021) with three within-pair factors for each family: session (before vs. after the break in the middle of joint play), condition (SAME vs. DIFFerent obstacle visibility) and block step (accumulating data in parallel with the intervals at which we ask questions, that is, for the first 4, second 3 and final 3 trials of one block). In particular, we determined p-values based on parametric bootstrapping and a modified ANOVA-type statistics (MATS) that can account for potential heteroscedasticity as well as singular covariance matrices, thus relaxing the assumptions of the model, and providing more reliable results with small sample sizes (Friedrich & Pauly, 2018).

*Post-hoc tests*: we used the same approach (and toolbox) to perform repeated measures ANOVAs for each of our measures of observation, again determining p-values based on parametric bootstrapping and ANOVA-type statistics (ATS) (see Friedrich & Pauly, 2017; Brunner, 2001). In both cases, we corrected for multiple comparisons using the Benjamini-Hochberg approach (Benjamini & Bochberg, 1995; Haynes, 2013) to control false discovery rates (FDR). Note that this correction further included the separate MANOVAs and ANOVAs that we calculated at the level of the trial (*see Chapter 3B, 'within trial dynamics'*), as well as all follow-up paired comparisons for significant effects of block or trial step. We corrected in five groups: one formed by all MANOVAs (4 families of observation * 8 effects [3 main effects + 3 two-way interactions + 1 three-way interaction + separate MANOVA for main effect of trial]), and one by all ANOVAs and post hoc paired comparisons we calculated for each family of observation (number of measures in a given family * [8 above effects + post hoc tests for significant effects of block step]).

**Results**

**Social experience as sensorimotor coordination: can participants' ratings be predicted from game-concurrent observations and personality differences in the team?**

Our linear mixed effects modelling approach yielded significant predictors of experience from each of our three levels (channels) of observation. *Figure C3A.4* presents an overview of all final models (*Figure C3A.4A*) as well as the results from our leave-one-out cross-validation (*Figure C3A.4B*).

In case of the engagement ratings, the final set of predictors includes the number of targets ($t = 4.143$, $p < .001$, estimate = .116), variability of relation ($t = 2.486$, $p = .014$, estimate = .030) and joint play DIFF ($t = 2.213$, $p = .028$, estimate = .023) as positive predictors, as well as the total path length ($t = -3.267$, $p = .001$, estimate = -.068) and time ($t = -6.969$, $p < .001$, estimate = -.027) as negative predictors. While more targets, greater variability in the strength of relation between players and the joint play DIFF condition predict *higher* engagement ratings, longer paths and later time predict *lower* engagement ratings. The random intercept over pairs captures 67 % of the total variance, indicating a higher relevance of pair difference compared to our results for agreement and predictability ratings (see below). Concerning the generalisability of this model, the cross-validation of fixed effects yields highly significant and strong correlation between predicted and observed experience ratings for repeated measures ($r = .454$, $p < .001$), but not for pair average values ($r = .12$, $p = .58$). This is congruent with the significant impact of the factor time on engagement.

Our final model to predict participants' agreement ratings includes the number of targets ($t = 3.704$, $p < .001$, estimate = .059), total path length ($t = 2.532$, $p = .012$, estimate = .033) and variability of relation ($t = 1.971$, $p = .050$, estimate = .015) as positive predictors, and extraversion differences between players ($t = -2.194$, $p = .041$, estimate = -.050) as a negative predictor. As such, while more targets, greater total path lengths and higher variability in the strength of relation predict *higher* agreement ratings, greater extraversion differences predict *lower* agreement ratings. The random intercept for pairs furthermore captures 54 % of the total residual

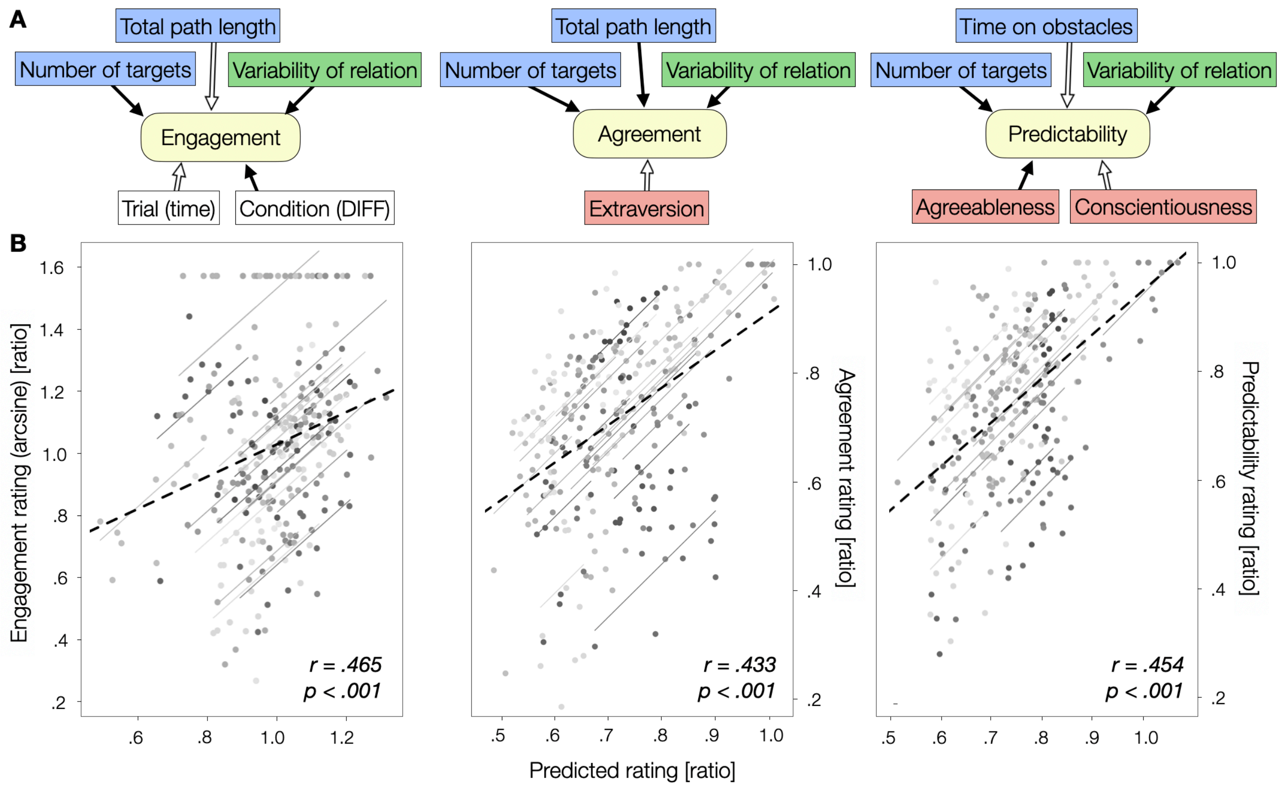



**Figure C3A.4** Linear Mixed effects Models of Participants' Experience Ratings. **(A)** Overview of the final model of engagement (arcsine transformed), agreement and predictability ratings. Filled arrows indicate positive relations, empty arrows a negative influence. In line with the overview presented in Figure C3A.3, the colour of the predictors indicates their family membership (***blue***: gaming behaviour, ***green***: finger movement, ***red***: personality traits). **(B)** Results from the leave-one-out cross-validation of the fixed effects based on repeated measures correlation of observed and predicted ratings (12 values per pair). The dashed bar displays the group average repeated measures fit - solid lines present individual pair fits.

variance, indicating that a significant proportion of variance can be explained by pair differences. Our cross-validation of fixed effects further yields highly significant and strong correlation between predicted and observed experience ratings ($r = .433$, $p < .001$ for repeated measures; $r = .486$, $p = .019$ for the pair average), speaking to the generalisability of our findings.

Concerning participants' predictability ratings, the set of winning model parameters includes the number of targets ($t = 5.784$, $p < .001$, estimate = .066), the variability of relation ($t = 2.363$, $p = .019$, estimate = .016) and the agreeableness differences between players ($t = 2.424$, $p = .024$, estimate = .047) as positive predictors, as well as the time spent on obstacle regions ($t = -2.088$, $p = .038$, estimate = -.021) and the conscientiousness differences between players ($t = -2.087$, $p = .049$, estimate = -.040) as negative predictors. Thus, while more targets, larger agreeableness differences and greater variability in the strength of relation between players predict *higher* predictability ratings, more time spent on obstacles and larger differences in conscientiousness predict *lower* predictability ratings. In post-hoc tests for a relationship between agreeableness differences and time lag, we saw a positive correlation for small to intermediate levels of agreeableness difference that inverts at a very high level of interpersonal difference (see *Appendix I, Supplementary Materials B*) - we return to this in the discussion. Similar to the result we see for our model of agreement ratings, the random intercept over pairs captures 52 % of the residual variance. The cross-validation of fixed effects in turn yields highly significant and strong correlation between predicted and observed experience ratings ($r = .454$, $p < .001$ for repeated measures) in particular when aggregating results over time ($r = .632$, $p = .001$ for the pair average).

**Changes over time and across game conditions: do our observations change across sessions, block steps and joint-play conditions?**

Our analyses of variance (ANOVA) included three within-pair factors (condition, session and block step) as well as all two- and three-way interactions between them. Below, we summarise significant results from each level of observation, jointly discussing results for all measures of experience ratings, gaming behaviour and finger movement, respectively. We always begin by reporting results from a multivariate ANOVA (MANOVA) that integrates all measures from a given family. Next, we report results from individual measure ANOVAs (including post-hoc pairwise comparisons for significant effects of block step). *Figure C3A.5* illustrates main effects for candidate measures from each family of observation - here, we selected effects that show the highest significance levels, and sought to present different measures rather than the same measure twice. *Figure C3A.6* in turn presents the only two significant interaction effects that we observed. Both figures illustrate the distribution of pair mean values by means of violin plots: beyond the median, interquartile range and outliers (single dots in the distribution), these plots show the probability density of the data at different values (Hintze & Nelson, 1998).

*Appendix I, Supplementary Materials C,* presents a table that lists all family-wise MANOVA and individual-measure ANOVA results, as well as the pairwise post hoc comparisons we performed for significant effects of block step. For a complete set of visualisations of significant ($p < .05$) main and interaction effects, further see *Appendix I, Supplementary Materials D*.

In case of the **experience ratings**, the MANOVA revealed a significant main effect of block step only (MATS = 10.086, $p = .009$). In the individual ANOVAs, we in turn found a significant effect of block step only on engagement: engagement *drops* (ATS = 8.679, $p = .017$), in particular from the

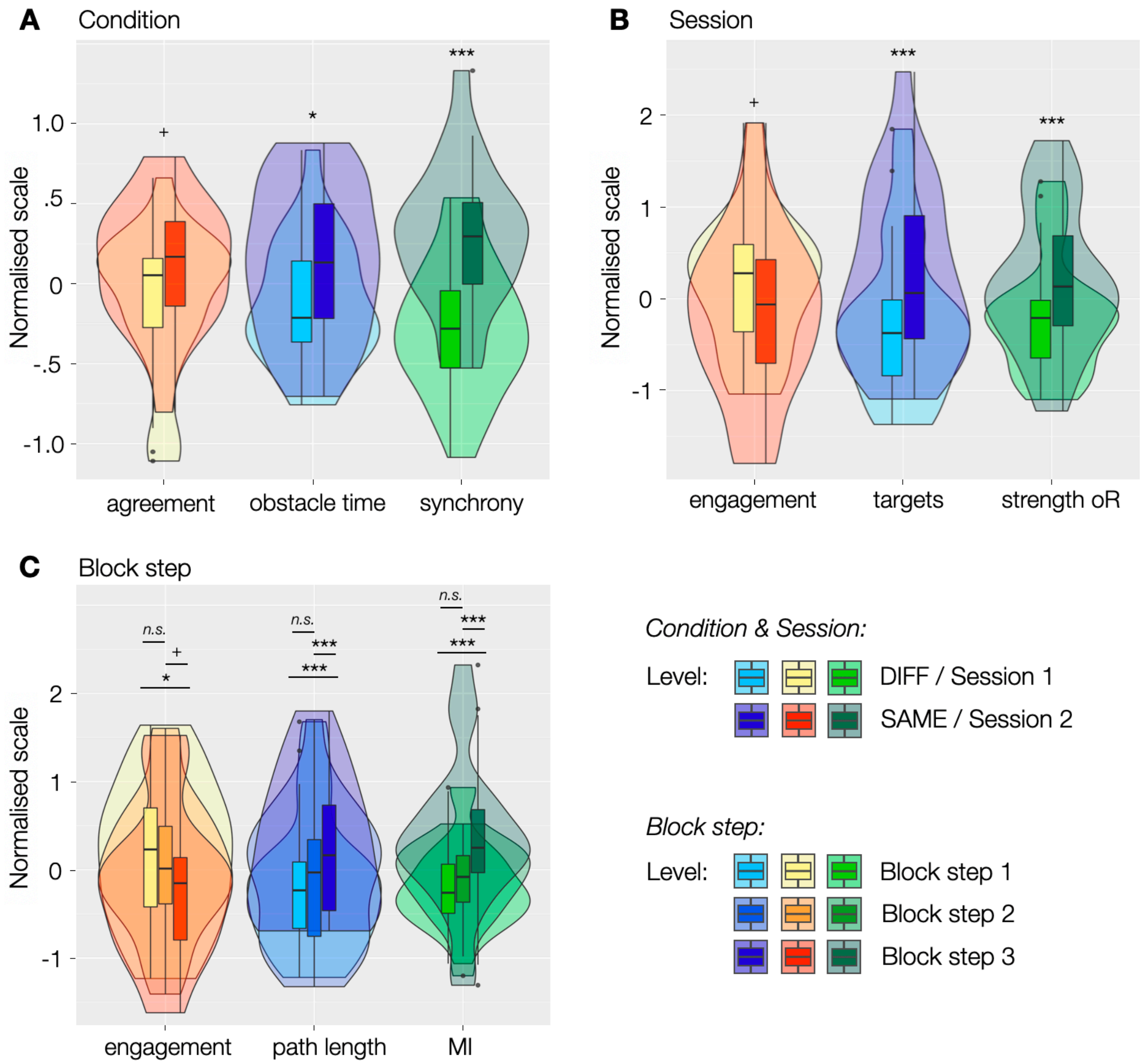



**Figure C3A.5** ANOVA Main Effects of Condition, Session and Block Step for Candidate Measures from each Family of Observation. Within-family FDR corrected p-values are indicated by *** ($p < .001$), * ($p < .05$), + ($p < .10$) or *n.s.* ($p >= .10$). **(A)** Main effect of Condition. Agreement tends to be higher in joint play SAME, players spend less time on obstacle regions in joint play DIFF, and show higher levels of synchrony in joint play SAME. **(B)** Main effect of Session: engagement tends to be higher in the first session, whereas players collect more targets and their steering movements are more strongly related in session two. **(C)** Main effect of Block Step. engagement drops over block steps, whereas path length and mutual information increase - in all cases in particular from the first (and second) to the third block step. Note that significance levels are here indicated for pairwise comparisons between individual block steps (as denoted by the lines below the symbols).

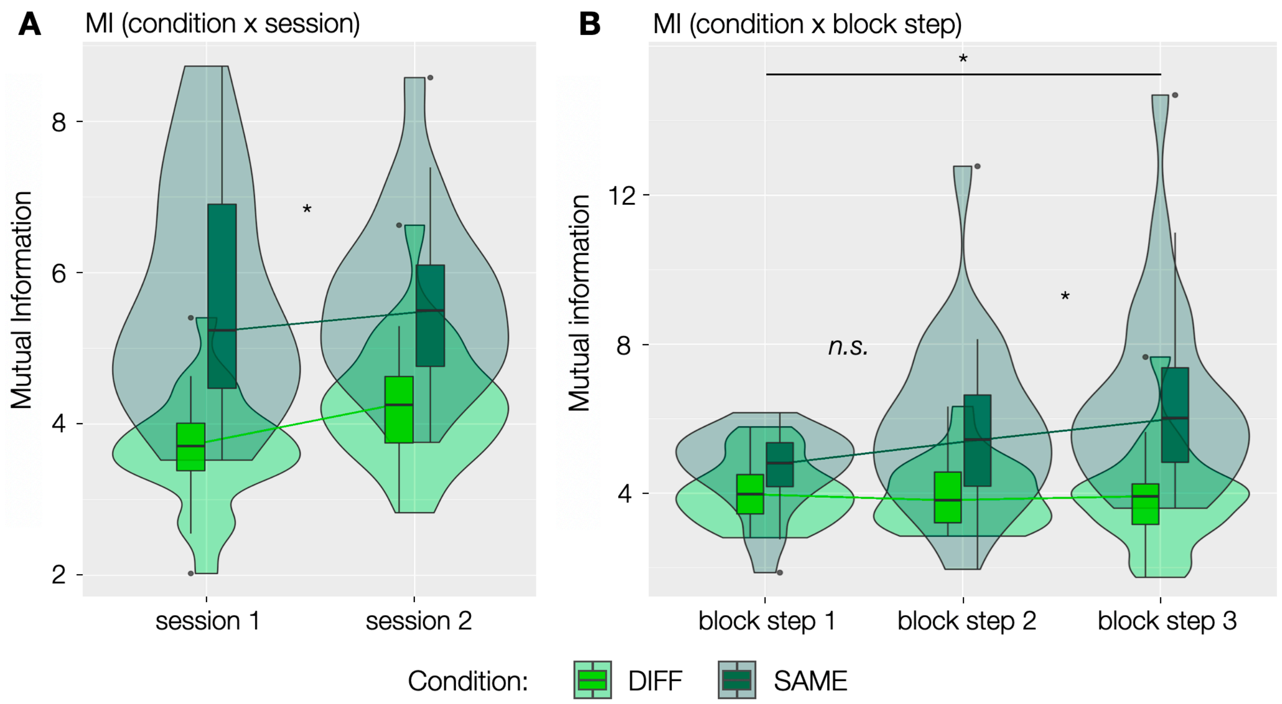



**Figure C3A.6** Significant Interaction Effects in the post hoc ANOVAs. Within-family FDR corrected p-values are indicated by * (p < .05), or *n.s.* (p >= .10). **(A)** Interaction of condition and session. MI increases more strongly over sessions in joint play DIFF, compared to joint play SAME. **(B)** Interaction effect of condition and block step. MI increases more strongly in joint play SAME, compared to joint play DIFF, from the second to the third block step.

first to the third block step (ATS = 16.536, p = .017). In summary, experience ratings do not vary systematically as a function of time or conditions, with the only significant change being a drop in engagement over block steps.

Concerning measures of **gaming behaviour**, we found significant main effects of session and block step (session: MATS = 33.024, p = .009, block step: MATS = 17.010, p < .001). The individual ANOVAs showed significant differences for targets, obstacle time and path length over sessions and block steps. Specifically, the number of targets collected increased (session: ATS = 29.146, p < .001; block step: ATS = 8.43, p = .003), obstacle time decreased (session: ATS = 7.17, p = .024; block step: ATS = 9.078, p = .005) and path length increased (session: ATS = 10.296, p = .008; ATS = 13.911, p < .001). In particular, we reliably saw differences (improvement) between the first and third block step (targets: ATS = 15.749, p < .001; obstacle time: ATS = 23.39, p < .001; path length: ATS = 22.633, p < .001) as well as the second and third block step (targets: ATS = 7.867, p = .033; obstacle time: ATS = 11.167, p = .006; path length: ATS = 21.21, p < .001). Targets and obstacle time furthermore displayed a significant effect of condition (more targets in SAME: ATS = 6.807, p = .030; less obstacle time in DIFF: ATS = 5.896, p = .046). In summary, participants became overall better (they collected more targets, spent less time on obstacle regions, and travelled longer distances with the ball) over sessions and block steps. Gaming behaviour looks a bit more diverse across the two joint play conditions: while participants collected more targets in joint-SAME, they spent less time on obstacles in joint-DIFF trials, with no difference between the two conditions in path length. Finally, target sequence complexity appears to be highly stable in time and across conditions.

Our analysis of **basic finger movement** parameters revealed no significant effects at the level of the family or in individual measure ANOVAs. In other words, basic movement parameters do not vary systematically over sessions, block steps and game conditions.

Finally, the MANOVA of our family of **finger movement coordination** measures revealed significant main effects of both session and condition (session: MATS = 35.820, $p = .006$, condition: MATS = 97.491, $p < .001$). Through our individual measure ANOVAs, we saw that several coordination measures increased from the first to the second session (synchrony: ATS = 18.647, $p < .001$; strength of relation: ATS = 20.249, $p < .001$) and were higher during joint play SAME compared to DIFF (synchrony: ATS = 34.137, $p < .001$; strength of relation: ATS = 19.913, $p < .001$; MI: ATS = 40.549, $p < .001$). For MI, we additionally saw a significant increase over block steps (ATS = 13.027, $p < .001$): in particular, MI increased from the first (ATS = 15.27, $p < .001$) and second (ATS = 16.252, $p < .001$) to the third block step. This increase in MI furthermore differed across conditions (ATS = 9.912, $p = .020$), with a more pronounced increase from the second to the third block step in joint play SAME (ATS = 10.795, $p = .020$). On the other hand, MI increased more strongly over sessions in joint play DIFF versus SAME (ATS = 7.77, $p = .046$). In summary, we found that movement coordination generally increased over sessions, and was higher in joint play SAME compared to joint play DIFF for undirected measures of coordination. In case of MI, the increase in coordination over *sessions* was more pronounced in joint play DIFF, whereas the increase over *block steps* was stronger in joint play SAME towards the end of the block.

**Discussion**

Overall, the present work contributes to social interaction research in three distinct ways. First, we present a novel paradigm for the study of motivated and continuous sensorimotor interaction between two players. Second, we generated detailed records of interpersonal coordination and relate dynamics across multiple levels of observation. In particular, we used several operationalisations of sensorimotor coupling in a social context, and assessed the influence of the interaction context, personality traits, gaming behaviour as well as interpersonal movement coordination on social experience. Third, we highlighted moments of target collection and greater variability in the strength of interpersonal coordination as predictors of enhanced social experience. Together with our (mixed) findings about the impact of shared versus complementary information between players about the game environment, our results point to a dual importance of both synchrony and variability for positive social engagement.

We now revisit our experimental design and findings in more detail.

The BallGame presents a **novel paradigm in social interaction research**. Our experimental design can be situated between tasks that demand or centrally involve rhythmic interpersonal coordination (Konvalinka et al., 2010; Dumas et al., 2010; Dumas et al., 2014a; Llobera et al, 2016;

Zhou et al, 2016; Vesper et al, 2016; Varlet et al, 2020) and experimental approaches that focus on natural interactions (Ramseyer & Tschacher, 2016; Kimmel et al., 2018; Jakubowski et al., 2020). The BallGame is explicitly set up at their intersection: interactional synchrony presents an advantage but is not the goal in this experimental task. Communicating and finding agreement based on individual preferences and complementary viewpoints and actions is furthermore equally relevant. As such, the BallGame leaves room for individual and interactional autonomy around the development of interpersonal coordination. To put to test the close relationship between interpersonal sensorimotor coordination and social experience identified in the cited research on rhythmic coordination and more natural social interactions, we combined autonomous social engagement with detailed multi-level observation. Importantly, the BallGame involves continuous interpersonal sensing and acting, overlapping possibilities for action and shared as well as complementary information between players. Our analytic approach further considers changes over time and context (information availability), and integrates in-depth assessment of participants' first-person experience - a novel approach in laboratory studies of interpersonal coordination (see in particular *Chapter 3B*).

In our primary analysis, we integrated **multiple levels of observation** and focused in particular on **interpersonal sensorimotor coordination as a predictor of social experience**. This approach was motivated by recent proposals to ground social cognition in interpersonal coupling mechanisms (Lübbert et al, 2021). Our analysis demonstrates that social experience in the BallGame was influenced by dynamics at each of our levels of observation: gaming behaviour (especially the number of targets), movement coordination (in particular the variability of relation between players), personality differences as well as the larger interaction context (time and game condition).

We consistently found a higher number of **targets** collected as well as greater variability in the strength of relation between participants' finger movements to be associated with higher experience ratings. Good performance is a straightforward predictor of experience - setting and achieving reachable goals is at the heart of motivation and sustained engagement. Noticing that you are good at something reinforces engagement and learning (see e.g. Krath et al., 2021). The dominant influence of a performance measure on experience fits with Llobera and colleagues' (2016) findings, which equally show relatively weak influence of personality and task related variables on social experience, as compared to performance. An increase in the variability of the peak strength of relation between players' movements (independent of the lag between them) is a more surprising predictor of experience. We interpret this finding as a positive impact of a more flexible relationship between players on their experience of the interaction. This could explain why engagement ratings are reduced in the joint play SAME condition: social engagement benefits from (a certain kind and degree of) variability, which may in turn be enhanced by having in part complementary views of the situation. A **special role for variability in social interactions** - next to a positive impact of synchronous or otherwise coordinated behaviour - is in line with Proksch and colleagues' (2022) finding of a parallel increase in stability *and variability* over the course of an orchestra performance explicitly designed to transition from uncoordinated to coordinated behaviour. The authors applied recurrence quantification analysis to sound recordings of the performance - variability in this case refers to recurrent sound (amplitude) sequences of variable length. Early work on interactional synchrony in the movements and vocalisations of a conversing group also points to variations in interpersonal synchrony as a key mechanism for coordinating switches in communicative role (Kendon, 1970). We also find support for a dual importance of synchrony and variability in theoretical literature. For instance, De Jaegher (2007), in her account of cognition as participatory sense making, argues for the central role of variability: "social interactional timing is a variable affair, and not rigid". Importantly, the polarity we see between variation and synchrony resembles the balance between exploring and exploiting that is central in psychological attachment (Bowlby, 1982), foraging (Stephens et al, 2008; Hills et al, 2015), fun (McCullough, 2013) and creativity (Hart et al, 2017). Our interpretation also speaks to predictive coding theories of neural and cognitive function (e.g. Clark, 2016). In a nutshell, predictive coding argues that cognitive functions (and our nervous system) continuously oscillate between generating models about meaningful aspects of our environment (predictions, hypotheses), and identifying exploratory behaviours that are best suited to probe and fine-tune them. In this view, cognition would balance reliable assumptions with their effective exploration. At another level, the suggested balance between stability and variation can be compared to a co-existence of integrative and segregative tendencies that is pointed out in dynamical systems theory (Tognoli & Kelso, 2014). Overall, we see strong evidence for an important role of variation in social sensorimotor coordination: successful interpersonal engagement seems to require room and sensitivity for differences just as much as it relies on the capacity to synchronise and integrate them in shared forms of acting and understanding (see also Sebanz et al, 2006).

When taking a closer look at interpersonal dynamics under shared (joint play SAME) versus in part complementary information among players (joint play DIFF), we found that undirected measures of coordination (synchrony, strength of relation, MI) were higher in joint play SAME, when players saw the same obstacle regions. We also saw a stronger increase in MI over block steps in the joint play SAME condition (and a congruent trend for overall higher agreement ratings during joint play SAME). In contrast, longer-term increases in movement coordination may have been driven by effects in the joint-play DIFF condition: MI increased more strongly over sessions in joint play DIFF, versus SAME (a pattern that also emerged as a trend for synchrony). We likewise did not see homogeneous differences in performance between the two joint play conditions: players collected more targets in joint play SAME, spent less time on obstacles in joint play DIFF, and travelled equal distances in both conditions. Thus, congruent with the hypothesised dual importance of both synchrony and variation for engaging social interactions, it seems that both **shared and complementary information** can benefit interpersonal engagement, coordination and performance.

Besides the positive effect of collecting many targets and moving at variable strengths of relation that we identified for all three experience ratings, the winning models of players' agreement and engagement ratings additionally included **path length**: travelling longer paths decreased engagement, but increased agreement ratings.

The latter makes intuitive sense: the more we agree, the further we can travel together - the further we can travel together, the more we seem to be in agreement. The negative impact of path length on engagement, in turn, might arise from learning effects as well as a compromise between exploring novel, and exploiting proven strategies: learning together through exploratory behaviour and challenging moves is likely more engaging (Lucas, 2018), but also more demanding and thus less productive (in terms of ground covered). Indeed, our analyses of variance showed that engagement and path length follow opposite trajectories at the level of sessions and block steps: while path length increases, engagement drops. Exhaustion might also play a role: over time, players may be less motivated to explore and instead seek to avoid the frustration of running into obstacle or creating misunderstanding within the team by deviating from a once agreed upon path. As such, they resort to accomplishing their main task - collecting as many targets as possible - possibly at the cost of interactionally more complex and stimulating behaviour.

Finally, several measures are only present in one of the three models: later time decreases engagement, more time on obstacle regions and differences in trait conscientiousness reduce predictability, and while differences in trait extraversion *decrease* agreement, differences in trait agreeableness *increase* agreement.

The negative influence of time on engagement is also visible as a reduction in engagement ratings over both sessions and block steps, and likely relates to **fatigue** from repetition. The negative impact of obstacle time on predictability, in turn, might reflect differences between players in their **strategic preferences**. For example, players may want to steer the ball through or around obstacles, explore new or repeat old paths, and display more fine-grained differences in steering behaviour, all of which can cause difficulty to move the ball in a coordinated fashion and thus make it more likely for players to find each other unpredictable - and end up stuck on obstacle regions. Next, the association of smaller conscientiousness differences with higher predictability ratings suggests that **similar levels of ambition and discipline**, in particular, make players predictable for one another in this kind of social interaction. In other words, when highly conscientious - ambitious, disciplined and orderly - players are teamed with a partner who cares less about top performance or is more open to exploring alternative courses of events, this might cause a lack of understanding and shared modes of play within the team. Likewise, we find that greater **similarity in trait extraversion** - the tendency to be active, optimistic, interested in communication and exciting stimulation - leads to higher agreement ratings. Our findings about a negative impact of personality differences on social experience could be related to observations of team-work processes in which interpersonal differences (in position within a power hierarchy as well as individuals' conceptual approach to the task) caused 'boycot' (deviation from the plan) and as a consequence less effective collaborative task solutions (De Brabander & Thiers, 1984).

Interestingly, we find that **agreeableness differences** have the opposite effect: teams of players with distinct tendencies for altruistic, empathic, understanding or benevolent behaviour give higher predictability ratings. We speculate that this finding might relate to asymmetric roles in the interaction: one player might pick up a more proactive role, while the other, more agreeable player, seeks harmony and integrates suggestions in order to maintain cooperation. We could indeed identify such a relation at small to intermediate levels of interpersonal difference. Relatedly, a study of joint creative processes showed that the ability to express and integrate different viewpoints within a group is an important creative resource (Bjørndahl et al, 2015). As such, pairs of players with (intermediate) agreeableness differences may have been more prone to generate *and* integrate different viewpoints. It would be interesting to link these predictions to findings on stronger (movement driven) modulation of neural activity in followers (Dumas et al, 2010; Zhou et al, 2016) - in particular, whether 'follower-typical' neural modulation is enhanced in participants with higher levels of agreeableness.

Our approach does not yield simple (nor final) answers about the relationship between interactive movement coordination and social experience.

In future work, our modelling approach could be improved so as to consider mediating relations that we identify between our predictors - most importantly interrelations between movement coordination and personality differences as well as performance (see also *Chapter 3B*). Beyond that, our dataset holds further untapped potential: the integration of game-concurrent eye-tracking and EEG recordings is likely to add further detail and complement our framework of analysis with additional research questions, as we continue to trace differences in social experience and personality in measures of interpersonal coordination. As such, we may reach a yet more comprehensive description of social interaction in the BallGame.

**Future lines of investigation** should follow the particular kind of variability (combination of synchrony and variability) that is important for social interaction - that is, for smooth coordination as well as the experience of being socially engaged. A promising strategy to advance our understanding of the complex balancing processes at play during social interactions could be different methods to assess changes in experience over time and across pairs and participants (see e.g. the dynamic ratings of togetherness in Noy et al, 2015; or the moment-by-moment micro-phenomenological investigation of interaction dynamics in Kimmel et al, 2018). Such data could highlight circumstances under which interactions are perceived as particularly engaging. Another option would be to include interview questions that specifically target the aspect of (un)predictability and variation in a social interaction. In addition, it may take experimental designs that accelerate the integration of different viewpoints, and allow complementary information to enter and benefit the coordination process. Under such circumstances, it would be interesting to contrast shared / familiar (cf. joint play SAME; similar personality) with complementary / challenging scenarios (cf. joint play DIFF; large personality difference). We hypothesise that under the right circumstances, the benefit of complementary information (propensities, skills) between players should outweigh their cost in coordination. Alas, granted opportunities to develop shared understanding, complementary scenarios should generate higher levels of mutual adaptation and learning, equal or better performance and as such overall richer social experience.

Future research is also needed to refine multi-channel assessment of social interaction. As mentioned before, alternative solutions to assess differences in experience over time and across pairs and participants should be explored. Methods that work at a meso-scale (between *momentary* movement coordination and *global* measures of experience or personality) might be especially fruitful to bridge qualitative and quantitative perspectives on social interaction. For instance, future approaches could be inspired by Interaction Analysis as presented in Hall and Stevens (2015): here, momentary interpersonal coordination acts (in posture, bodily movement, speech) are considered in terms of how they create a structure that involves actors, artefacts and their larger environment in shared meaning-making activity. A recent example of such an approach to studying social interaction dynamics is provided by Kalaydjian and colleagues (in press). Here, the authors investigated how a group of children engaged in free play shifts between exploring new and exploiting proven strategies. Their findings emphasise the distributed and collective nature of accomplishing such shifts in shared gestures of suggestion, recognition and confirmation.

The BallGame allowed us to explore dependencies and relations between interactive movement and social experience. Relating spatio-temporally highly resolved (movement coordination) with more integrated observations of engaged social interaction (experience, gaming behaviour, and personality), our work created bridges between different perspectives on interpersonal dynamics. We also demonstrated the utility of laboratory tasks that allow participants' continuous and motivated interaction for the integrated study of collaborative action. As such, we hope to have contributed to the study of social cognition as a complex and dynamic phenomenon.

# CHAPTER 3B

## The BallGame - In-depth Participant Reports and Follow-up Analyses

### Introduction: in-depth participant interviews to ground quantitative observation

To ground our multi-level quantitative observation of social interaction in the BallGame, we performed in-depth participant interviews at the end of the experiment. Here, we asked participants about their overall experience, particularly interesting or frustrating moments during the game, as well as their impression of the other and their collaboration.

Central themes that emerged in these interviews suggested follow-up analyses of our game concurrent recordings. First, participants' sustained focus on objects in the game environment prompted us to test whether the phase in the target cycle (approaching, departing from or traveling between targets) influenced the degree of movement coordination between players. We also assessed the influence of nearby (in)visible obstacles on the strength of relation between participants' steering movements. Next, several participants explicitly described a shift in their experience over the period of a trial - from social to performative. We followed up on these remarks with an ANOVA that compared behaviour during the first, second and final third of a trial. Finally, strikingly different remarks about the last block of individual play led us to pay closer attention to the performance of highly versus less coordinated pairs at the transition from joint to individual play.

Beyond these specific analyses, the results from the interviews contributed to our interpretation of findings from the analyses presented in *Chapter 3A*. In particular, they speak to the identified effect of personality differences on social experience, as well as the suggested influence of shared visual access on interpersonal coordination.

### Methods

For a description of the experimental task and protocol, see *Chapter 3A*.

### Individual participant interviews

At the end of the experiment, we conducted an individual interview with each participant. This presented them with an opportunity to report their experience of the BallGame on their own accord, beyond predetermined scales. Starting out with open questions ("What comes to mind when you think back to playing the BallGame?", "Which moments, if any, were exhausting/fun/social?"), the interview proceeded with more specific aspects of the game ("How hard was it to control the ball through your finger movements when playing alone vs. together?", "On a scale from 0 = '100% PC game' to 10 = '100% social interaction', how did you experience the joint play period?"). The interviews offer a rich description of participants' experience with the BallGame. We provide the full interview sheet in *Appendix I, Supplementary Materials F*.

### Thematic content analysis

To systematically assess and draw conclusions from the interviews, we performed a thematic content analysis following Elo and Kyngäs (2008) and Kuckartz (2012). Accordingly, we inductively developed a coding scheme that was tested by means of an iterative coding and refining procedure until a quarter of the data could be classified completely and unambiguously. We then continued to code the remainder of the dataset, occasionally merging or refining codes to avoid very small categories (containing less than 5 of the 46 individuals), or to accommodate novel content.

### Within-group differences in the interviews

To test for the influence of coordination, performance or personality differences on the themes that participants mention in the interview, we compared the number of individuals who mention a given code from pairs with low versus high performance, coordination and personality differences, respectively. To assess significant differences, we calculated a chi-squared statistics for each of the codes identified in the thematic content analysis.

### Movement coordination in relation to targets and obstacles

To assess the relationship between game landscape and sensorimotor coordination, we related the strength of relation to the time that has passed since the last target was collected - that is, over the target collection cycle. For each moment of ppWLCC calculation, we identified the fraction of frames that have past until the next target is collected. We then calculated the mean and standard error of the strength of relation between participants' finger movements in 20 equally sized (number of entries) sub-sections along the target collection cycle - beginning and ending in the moment a target is collected. We did so separately for the two joint play conditions (SAME versus DIFF), and tested for difference between the conditions in each of the 20 segments along the target cycle (Benjamini-Hochberg correcting p-values for the number of bins). For each moment of ppWLCC, we furthermore determined the visibility of the obstacle that was closest to the ball (minimal distance to the borders of any of the nine obstacles active on the current trial), that is, whether the obstacle was visible to both, either or none of the players. We then performed a repeated measures ANOVA with obstacle-visibility and game condition as within-pairs factors.

### Within-trial dynamics

To assess effects of trial step - differences between the first, second and third 20 seconds of a trial - we again first calculated a repeated measures MANOVA with trial step as the only within-pairs factor for each family of observation, followed by individual measure ANOVAs (Benjamini-Hochberg correcting p-values together with our analyses of variance across sessions, conditions and block steps - see above). Note that several measures of observation are excluded from the analysis over trial steps, because of insufficient or unavailable data at the level of the trial third, namely: experience ratings, target sequence complexity, PSI and MI.

**Shift from joint to individual play**

To follow up on participants' different experience of the final block of individual play, we performed a repeated measures ANOVA with block as within-pairs, and coordination as between-pairs factors, again determining p-values based on parametric bootstrapping and ANOVA-type statistics (ATS). We classified pairs as belonging to the high or low coordination group based on their aggregate rank on all seven measures of movement coordination (excluding the median pair from this analysis). We thus compared the number of targets collected by players from high versus low coordination pairs in the final block of individual play, with the number of targets they collected in the last two blocks of joint play.

**Results**

We begin by providing an **overview of our findings from the interviews**. The thematic content analysis of participant interviews revealed seven themes: game environment (Env), positive emotion (Pos), negative emotion (Neg), social presence (Soc), strategy (Str), individual play (Ind) and technical comments (x). *Figure C3B.1* presents an overview of the more detailed codes that specify each theme, illustrates how many participants talked about a given code, and highlights whether they played in a pair with small versus large personality differences.

Most of the themes we identified reflect participants' answers to one of our interview questions. For instance, we asked participants what it was like to play alone after the joint play period, and one of the themes that emerged from our analysis was 'Individual play'. Interestingly, we neither asked participants about the game environment, nor the technical setup, themes that nearly all players spoke about both in the early, openly phrased questions, as well as at later stages throughout the interview. Below, we summarise our findings from the interview with respect to key topics in our analysis. To get a more complete picture of participants' reports, find example quotes for each code in *Appendix I, Supplementary Materials G*.

Importantly, the data from the interviews provided a sanity check as to the social nature of the task: besides participants' nuanced experience of the interaction with their partner (see codes in *Figure C3B.1, Soc - social presence*), they answered on a scale from zero to ten that they experienced the game predominantly as a social interaction ('ten'), rather than a computer game ('zero') (mean = 6.45, standard deviation = 1.35). This is also reflected in the higher association of positive emotions with joint (n = 36 participants), compared to individual play (n = 10 participants).

Particularly relevant to our theme of joint action and movement coordination, we found that participants learned to coordinate better over time, both concerning the steering of the ball, as well as the interaction with their partner (Technical comments - sub-category of 'over time', n = 14 participants). They were furthermore concerned with figuring out what the other sees or intends to do (Strategy - 'listening where to go', n = 25 participants) in particular during the early trial period (sub-category of 'listening where to go', n = 10 participants). For instance, one participant describes playing together as "*waiting, what does my partner want - is what I want against this? Once this is settled, it is like playing alone*". Participants also talked about pondering

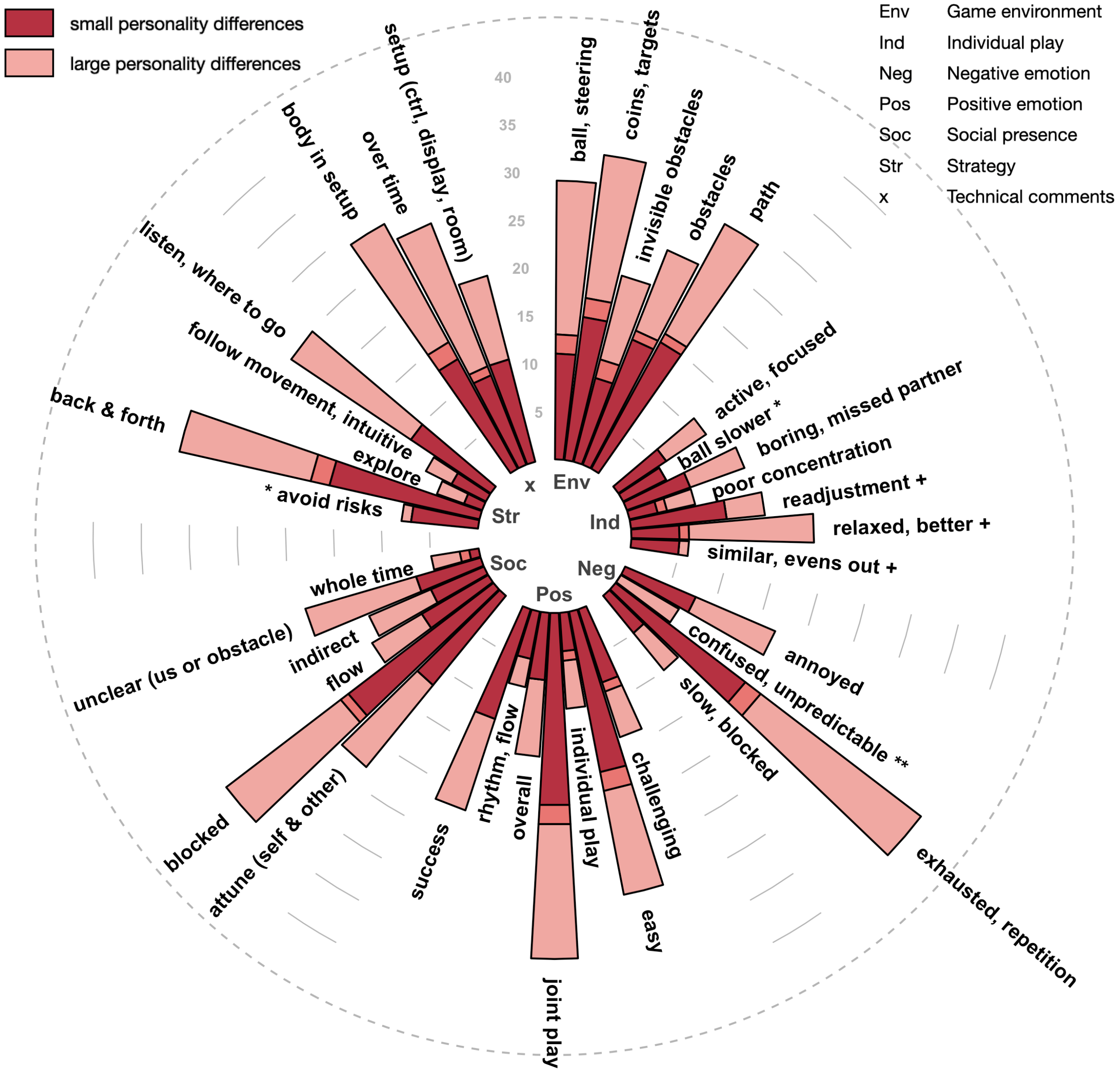



**Figure C3B.1** Thematic Content Analysis of Participant Interviews. Grouped radial bars reflect themes revealed by the thematic content analysis of participant interviews. The dashed line marks the total number of participants (46). The colour code indicates participants in pairs with small (dark red, n = 11 pairs = 22 participants) versus large (light red) aggregated differences in all measured personality traits (codes in the pair with median personality differences are displayed in medium-red). Asterisks mark interview-codes that differentiate participants from pairs with large versus small personality differences (chi-square p-values < .01 **, <.05 * and <.1 +).

whether the cause of slow ball movement was disagreement with their partner, or encounter with an invisible obstacle (Social presence - 'us or obstacle', n = 19 participants). Relatedly, they described moments in which difficulties were resolved as particularly pleasant and social (Positive emotion - challenge & joint play, n = 9 participants). Finally, a group of participants experienced a need to re-learn the game control when switching from joint to individual play, possibly indicating strong interpersonal attunement (Individual play - 'readjustment', n = 14 participants).

These results inspired additional analyses of our data. First, in spite of the lack of a respective question, all (!) participants repeatedly mentioned the objects in the game environment - targets, visible and invisible obstacles or the ball. This prompted us to investigate the influence of the game environment on the coordination of participants' finger movements. In particular, to compare the level of coordination across the 'target collection cycle' - that is, as a function of the time that has passed since the last target was collected. We also tested whether the (in)visibility of nearby obstacles impacted players' movement coordination ('obstacle visibility'). Second, several participants explicitly described a characteristic shift in their experience over the trial (n = 10 participants): during the early trial, they were concerned with the clarification of intentions, which they experienced as social and communicative. After identifying one path or strategy, they shifted their focus to steering the ball as best as possible along the agreed path. We therefore analysed the data over three 'trial steps' of 20 seconds each. Finally, when asked about the individual play period at the end of the session, some participants reported they were bored, felt the ball was slower, missed their partner or experienced an 'after-effect' - a need to re-learn to steer the ball (n = 22 participants). In contrast, another group of participants associated the final individual play period with relief and satisfaction: finally left to their own devices, they felt better, more relaxed and actively involved in the game (n = 20 participants). This divergence prompted us to take a look at within-group differences in the transition from joint to individual play. Note also that our comparison of pairs with large versus small personality differences (see colour code in *Figure C3B.1*) indicated that participants who played with a partner of *distinct* self-reported personality expressed more confusion, and tended to feel more relaxed in the final individual block of play - whereas players from teams of similar personality experienced the ball to be slower during individual play, talked more about avoiding risks and tended to experience individual play either as similar to joint play or felt a need to readjust their game.

**Influence of the game environment: do nearby targets and obstacles affect movement coordination?**

When comparing coordination as captured by the mean ppWLCC coefficient (strength of relation) across the target cycle, we found that the strength of relation is highest at and right after the moment of target collection (approximately 0 to 20% of the cycle), lowest around the third quarter (about 50 to 75% of the cycle), and overall higher in joint play SAME compared to DIFF, when participants see exactly the same obstacles (Benjamini -Hochberg corrected p-values < .05 for all 20 sections of the target cycle) - see *Figure 2B.2A* for an illustration of the effect.

In the ANOVA we calculated to compare the strength of relation when the ball is closest to an obstacle visible to both players, to when it is visible only to one or none of the players, we found significant main effects of both obstacle visibility and joint play condition (obstacle visibility: ATS = 57.247, p < .001; ATS = 7.382, condition: p = .016). *Figure 2B.2B* presents the main effect of obstacle visibility. In summary, coordination as captured by the mean ppWLCC coefficient (strength of relation) is clearly influenced by the objects in the game environment: it is higher at

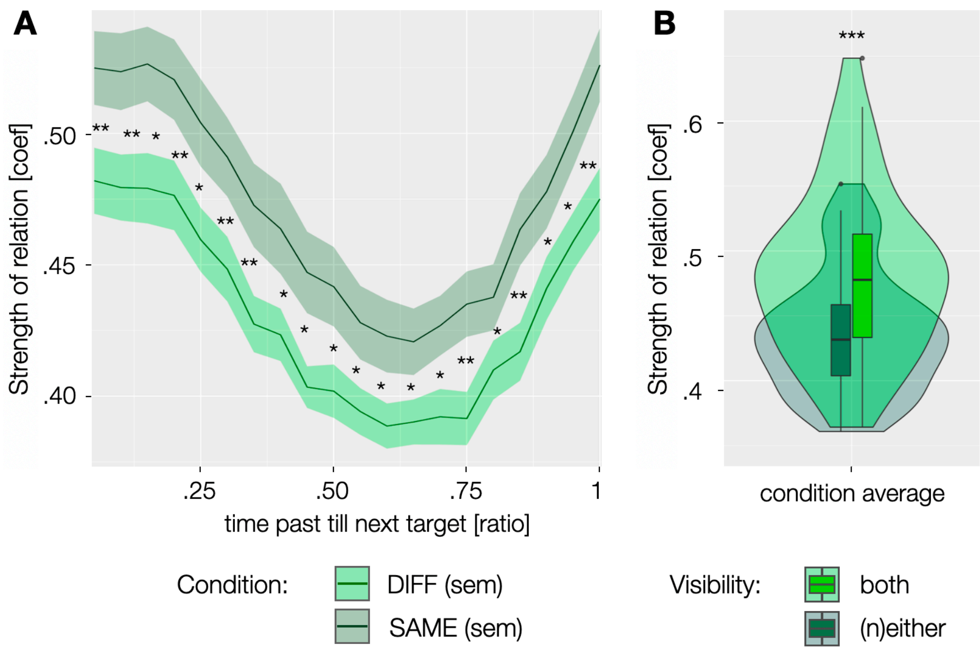



**Figure C3B.2** Coordination (Strength of Relation) depends on Objects in the Game Environment. **(A)** Strength of relation changes over the course of the target cycle. Lines and shaded areas indicate the mean and standard error of the mean (sem) strength of relation in 20 sub-sections along the target cycle. The strength of relation peaks right before and shortly after a moment of target collection, and is lowest after around two thirds of the time until the next target is collected. Throughout the target cycle, the strength of relation is higher in joint play SAME compared to DIFF (Benjamini-Hochberg corrected p-values are indicated for each sub-section: * < .05 and ** p < .01). **(B)** The strength of relation is higher when both players can see the obstacle that is closest to the ball. *** indicates p < .001.

and after target collection events, higher in joint play SAME versus DIFF, and higher when both players can see the most proximal obstacle, independent of the joint play condition.

**Within-trial dynamics: is the reported shift in experience from social coordination to performance reflected in other measures of observation?**

To test for within-trial effects in our game concurrent measures of observation, we performed MANOVAs the level of the family, as well as individual measure ANOVAs. Note that these analyses did not consider the effect of session, condition or block-step (see *Chapter 3A*).

At the level of the MANOVA, we found significant effects in all three families of observation: gaming behaviour (MATS = 203.487, $p < .001$), basic movement parameters (MATS = 3.902, $p < .001$) and movement coordination (MATS = 16.952, $p = .019$). All effects identified in the individual measure ANOVAs reflect an increase (in basic movement and movement coordination) or improvement (of performance) over the course of the trial. We found a homogenous group of significant effects across measures of gaming behaviour and basic movement parameters (targets: ATS = 19.732, $p < .001$; obstacle time: ATS = 154.998, $p < .001$; path length: ATS = 102.81, $p < .001$; distance: ATS = 21.79, $p = .001$; number of moves: ATS = 14.081, $p < .001$). In terms of movement coordination, we found significant effects for synchrony, strength of relation and time lag (synchrony: ATS = 8.511, p = .006; strength of relation: ATS = 13.255, p <.001; time lag: ATS = 8.476, p = .006).

The changes over trial steps follow distinct patterns - most strikingly concerning gaming behaviour (see *Figure C3B.3*): both the number of targets collected as well as the path length increases from the first to the second trial third (targets: ATS = 33.655, p < .001; path length: ATS = 123.326, p < .001). From the second to the third trial step, the number of targets collected drops (ATS = 44.522, p < .001), the time spent on obstacle regions also drops (ATS = 160.401, p < .001), and path length again increases (ATS = 10.75, p = .006). Performance generally increases from the first to the third trial step (targets (increase): ATS = 8.831, p = .012; obstacle time (decrease): ATS = 712.985, p < .001; path length (increase): ATS = 111.06, p < .001) (see *Appendix I, Supplementary Materials C* for a complete overview of the statistics, and *Supplementary Materials E* for illustrations of all significant effects over the trial step).

In summary, basic movement parameters increase over the trial, in particular from the first to the second trial third. Movement coordination increases over the course of a trial, especially towards the final trial third. Performance likewise increases over the course of a trial, with different trajectories in our three measures of gaming behaviour: while path length increases throughout the trial, the number of targets increases after the first 20 seconds, but participants collect most

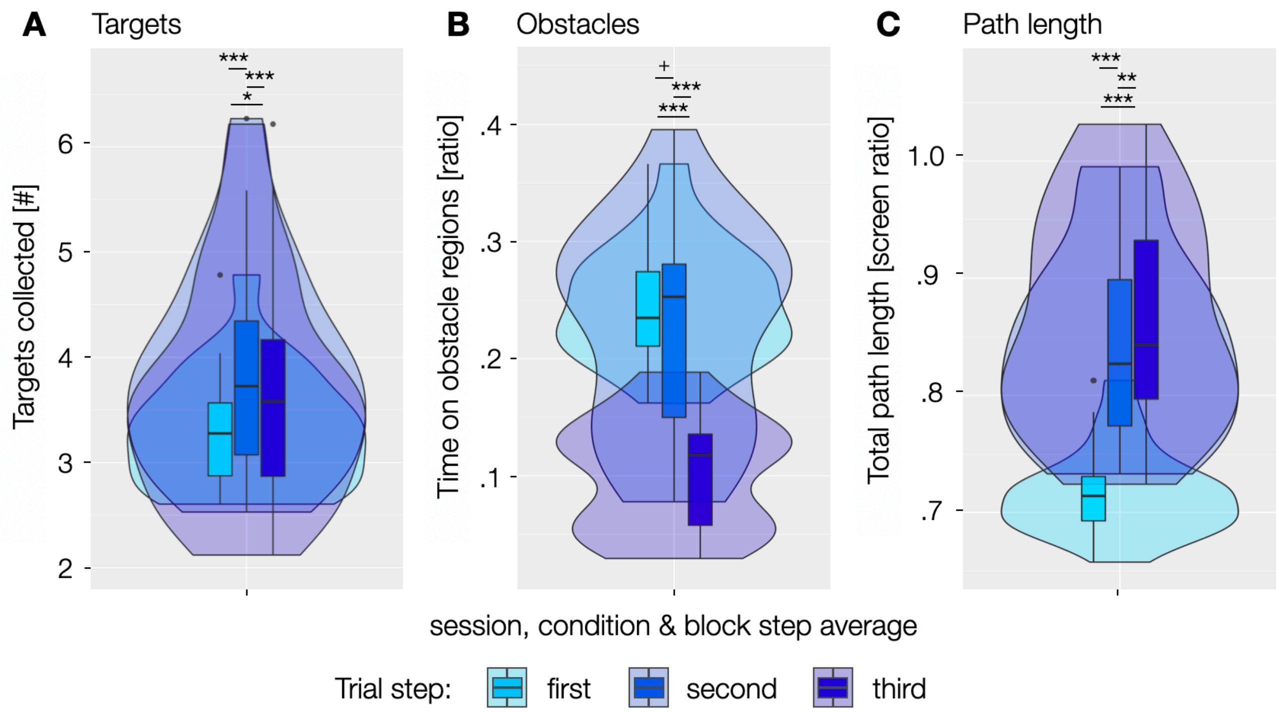



**Figure C3B.3** ANOVA Main Effect of Trial Step on Gaming Behaviour. Within-family Benjamini-Hochberg corrected p-values are indicated by *** (p < .001), ** (p < .01), * (p < .05), or + (p < .10). **(A)** The number of targets collected changes over trial steps: increasing from the first to the second and third trial step, and decreasing from the second to the third trial step. **(B)** Time spent on obstacles changes over the trial. In particular, it drops from the first and second to the third trial step. **(C)** Path length increases over the trial, in particular from the first to the second and third trial step, but also from the second to the third trial step.

targets in the second third of the trial. The time spent on obstacle regions, in turn, only drops significantly in the final third of the trial.

**Transitioning from joint to individual play: does interpersonal movement coordination correlate with shifts in performance?**

When comparing the number of targets collected in the last two blocks of joint as well as the final block of individual play in highly versus weakly coordinated pairs, we found a significant main effect of coordination (ATS = 17.378, $p < .001$), as well as a significant interaction effect of coordination and block (ATS = 9.903, $p = .002$). *Figure C3B.4* displays both effects. Thus, while highly coordinated pairs overall better performance drops when they switch to individual play, the overall weaker performance of players from less coordinated pairs increases during the final, individual block of play.

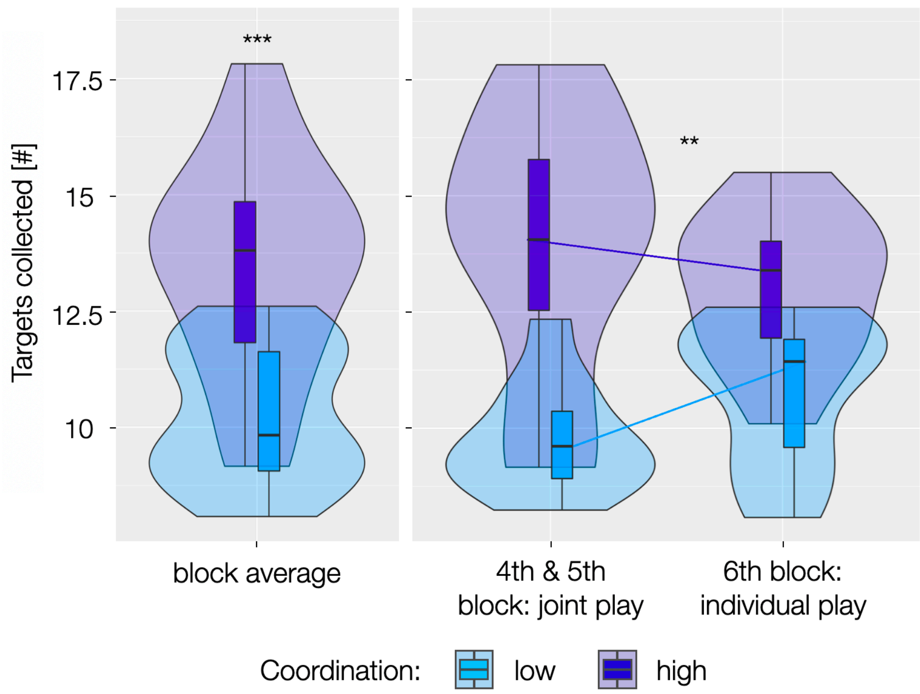



**Figure C3B.4** Transition from Joint to Individual Play. ANOVA of targets collected per trial in the final two blocks of the game. P-values are indicated by *** ($p < .001$) and ** ($p < .01$). **(left)** Main effect of coordination - coordinated pairs (and individual players from coordinated pairs) collect more targets. **(right)** Interaction effect of block and coordination: the change in the number of targets collected from the 4th and 5th (joint play) to the 6th block (individual play) is different in high versus low coordinated pairs. While players from coordinated pairs collect fewer targets as they play alone, players from uncoordinated pairs collect more targets in the final block of individual play.

**Discussion**

Our detailed investigation of participant reports highlighted the BallGame as a markedly social activity, and suggested important follow-up analyses. Prompted by participants' persistent mention of objects in the game environment, we revealed a strong influence of proximity to targets and mutually visible obstacles on players' interpersonal coordination. Unexpected reports of a shift in participants' experience over the course of a trial - from social interaction to performance - further led us to identify strong dynamics in gaming behaviour and movement coordination from the first to the second and final third of a trial. In particular, while the number of targets collected, the path length as well as basic movement increase immediately from the first to the second trial-third, obstacle time and several measures of movement coordination only improve significantly towards the end of the trial. Finally, inspired by participants' at times antithetical comments about the last block of individual play, we showed within-group differences when players shift from joint to individual play: the performance of strongly coordinated pairs drops, whereas players in less coordinated pairs show an increase in performance.

Our analysis of participant interviews not only delivered additional insight on interpersonal coordination in the BallGame. They also strengthened our confidence in the results we identified based on our models of game concurrent experience ratings as well as the analyses of variance presented in *Chapter 3A*.

To begin with **effects of time**: participants' remarks about their improving ability to steer the ball and coordinate with their partner are in line with the learning effects that we observed in measures of performance and movement coordination across sessions and block steps. Participant comments are also congruent with the decrease in engagement that we identified both in our analysis of variance as well as the mixed effects model of the engagement ratings. In particular, participants mentioned fatigue from repetition as well as a usually much higher interest in the game during the early to middle period of the experiment.

The analyses we performed in response to participants' expressed focus on game objects (ball, targets, visible and invisible obstacles) furthermore confirmed the important **role of shared visual access** for interpersonal movement coordination (as indicated by the higher levels of undirected coordination that we saw in joint play SAME versus DIFF). Specifically, we found that momentary proximity to targets and obstacles of shared visibility enhanced the strength of relation between players' veering direction (see *Figure C3B.2*). Of note: while we find that coordination is higher around obstacles that both players can see, participants explicitly point to moments in which difficulties are resolved as particularly pleasant and social. What is more, participants' reasons for experiencing the game as a social interaction rather than a computer game often involved descriptions of the unpredictable or variable behaviour of the ball and thus their partner. This suggests a more complex relationship between social experience, interpersonal coordination and the interaction context. In particular, these findings speak to a combined importance of both synchrony and variability for social engagement, as already suggested by results presented in *Chapter 3A*.

Participants' comments about **divergent strategic preferences** may further shed light on the negative impact of extraversion and conscientiousness differences that we observed in our models of game concurrent agreement and predictability ratings, respectively. While some players talked excitedly about exploration and challenge, aiming for optimal trajectories at the risk of obstacle collision, others valued reliability, avoided obstacles at large, and found it natural to stick to the first agreed upon path between the same two targets. What is more, the level of similarity versus differences in personality among coordinating players seems to have affected their experience of the game, especially concerning the final individual play period, but also potential negative emotions and strategic preferences. In further analyses, it would be interesting to test for a measurable relation between voiced strategic preferences in the interviews (explore-challenge-risk vs. reliable-safe-repetition) and our personality data (trait extraversion and conscientiousness). Likewise, it would be useful to investigate within-pair agreement about the success and enjoyability of the interaction (or lack thereof) as a lens on potential within-group differences in our game concurrent observations. However, it should be noted that in our study the sample size is relatively small, making it hard to consider anything but two sub-groups of relatively equal size.

Prompted by participants' remarks about the early period of the trial being more social, we looked at the development of performance and movement parameters over the course of a trial. Here, we found that in parallel with an increase in path length from the first to the second third of a trial, players' increasingly moved their fingers, collected more targets, and displayed shorter interpersonal time lags. Obstacle time, in turn, dropped only towards the final third of the trial - in parallel with a significant increase in synchrony and strength of relation. This group of effects fits with participants' reported early-trial engagement in social coordination (anticipating and reading the other, agreeing on where to go) and later-trial fine-tuning of their steering performance (avoiding obstacles along an agreed-upon path, traveling longer distances at a steady number of moves). Overall, these results provide strong evidence for within-trial dynamics and may provide important guidelines for our analyses of game concurrent eye tracking and EEG recordings. It would further be consequent to test if pairs who explicitly reported within-trial dynamics show respectively stronger within-trial changes in coordination and performance. Lastly, the **dissociation of *early* social engagement from strong movement coordination *at the end* of the trial** again suggests a more complex relationship between measures of movement coordination and reported social experience.

Finally, we saw that players from interpersonally coordinated teams' performance dropped (but remained overall higher), whereas players from less coordinated teams' performance increased (but remained over lower) at the moment of transitioning from joint to individual play. It would be interesting to test whether a similar pattern emerges for experience: do players from less coordinated pairs experience a surge in engagement, when they switch to individual play?

From the start, our experimental approach focused on the **integration of multiple methods** of observation as a means to better understand the relationship between interpersonal movement coordination and social experience. In *Chapter 3A*, we successfully predicted players' experience ratings from a combination of game concurrent behavioural records, the joint play condition, measures of within-pair personality difference and the time that participants had played together. We further highlighted learning effects and differences in our observations depending on whether participants had a shared or complementary view of the obstacles in the game environment. The analysis of in-depth participant reports that is presented in this chapter added further detail to these findings. In particular, we exposed the influence of (proximity to) targets and obstacles on interpersonal coordination, highlighted within-trial changes in the interaction dynamic, and pointed out differences between players at the transition from joint to individual play.

The present study demonstrates social sensorimotor contingencies as a conceptual framework that supports innovative research on interpersonal behaviour and experience. Our work corresponds well with another recent account of social coordination: in their perspective article, Vesper and Sevdalis (2020) elaborate on the multiple functions fulfilled by bodily movements in social interaction - from communicating emotions, goals and aesthetic judgement, to facilitating coordination by placing deliberate emphases that amplify and separate one way of approaching a situation from another. In congruence with our approach, the authors further highlight the influence of the task character, situational demands and individual differences in personality or ability on sensorimotor coordination. Indeed, our findings from the BallGame presented evidence for links between social experience and movement coordination, performance, objects in the game environment as well as personality differences between players. As such, our work - especially the analyses presented in this chapter - demonstrates the feasibility and effectiveness of research that combines careful attention to participants' experience and the interaction context, with precise quantitative observation and comprehensive statistical models.

## CHAPTER 4: THE SONIFIED MIRRORGAME

Chapter 4 presents work on the Sonified MirrorGame: a simple but engaging joint improvisation task in which two players move an avatar along a virtual line to produce interesting sounds and coordinated movements together. Building on previous experimental work, we complemented earlier versions of the mirror game with in-depth experience assessment and an additional sensory feedback modality: an interactive movement sonification that translates players' position and distance into a combination of orchestra sounds and noisy beats. While forming part of the European socSMCs research project, this work received additional support through independent funding I acquired to improve the integration of first and third person methods in cognitive science research ('Varela Award').

**Chapter 4A** presents an unpublished manuscript draft. It introduces the experimental task and protocol, as well as mixed effects models to predict participants' game concurrent experience ratings from the interaction context (sensory feedback modality, leadership instructions, time) as well as the level of interpersonal movement coordination. Additional ANOVAs highlight changes in movement coordination over time and across interaction contexts (visual versus audiovisual versus auditory play; leader-follower instructions versus joint improvisation).

Lübbert, A., Gonzàlez-Fernàndez, P., Göschl, F., Noy, L. and Engel, A. K. Social engagement in the Sonified MirrorGame - an interactive balancing act between synchrony and exploration. *In preparation*.

Author contributions: AL and PGF developed the experimental paradigm in exchange with AKE and FG. PGF and AL implemented the hard- and software environment of the game. AL conducted the study. FG and AL implemented the analytic approach, AL analysed the data. AL wrote this chapter in exchange with LN.

**Chapter 4B** presents work in preparation. It gives an overview of a thematic content analysis of individual interviews conducted with participants after the game. In particular, it summarises central themes voiced by participants and discusses their relevance for results identified in *Chapter 4A*.

Lübbert, A., Gonzàlez-Fernàndez, P., Göschl, F., Noy, L. and Engel, A. K. The Sonified MirrorGame - in-depth participant reports. *In preparation*.

Author contributions: AL and PGF developed the experimental paradigm in exchange with AKE and FG. AL developed and conducted the interview, and analysed the data. AL wrote this chapter in exchange with FG and LN.

**Appendix II** of this thesis provides supplementary materials to the work presented in *Chapter 4*, including a complete overview of statistics, visualisations of significant effects, the post-game interview and quotes from themes and codes identified in the thematic content analysis.

# CHAPTER 4A

## Social engagement in the Sonified MirrorGame - an interactive balancing act between synchrony and exploration

### Introduction: learning about the nature of interactively maintained dynamics

Social interactions are central to human life - beyond upbringing and family, most things we do or need involve others. Given the primacy of interacting and coordinating with other people, we investigate the ingredients of successful, in the sense of engaging, meaningful and productive social interactions: what does it take for social encounters to meet us where we are, call on our skill and creativity, to leave us and others with a lasting impression?

The approach taken by the present study is informed by research in the field of embodied and enactive cognition. This field of study puts the relational domain between individuals centre stage. In particular, we were inspired by the concept of socialising sensorimotor contingencies (Lübbert, 2021), which describes social behaviour and experience as interactively maintained dynamics of mutual influence at sensorimotor to cultural and physiological levels. To learn more about the nature of interactively maintained dynamics, researchers in the past have co-register movement dynamics of interacting individuals with changes in their experience and physiology (Zapata-Fonseca et al, 2016; Walton et al, 2018; Ravreby et al, 2022). Mirror games - scenarios in which two individuals perform the relatively open-ended task of creating coordinated motion together - provide one such example (Noy et al, 2011; Feniger-Schal et al, 2018).

In the present study, we performed a one-dimensional mirror game. Two participants stood in front of each other and coordinated their movements through a simple digital avatar that they slid left and right across the screen of a tablet. In different trials, they were instructed to either lead, follow, or jointly improvise movement with their partner. After each trial, participants rated their experience along several dimensions (such as 'fun - boring', 'chaotic - fluent', or 'felt long - went by quickly'). To arrive at more thorough descriptions of players' experience, we further conducted multiple interviews. In addition to that, we used an innovative method for participants to reflect on and report their current state: a 'map of emotions' task. As such, we complemented the standard protocol of the mirror game with in-depth subjective experience assessment, effectively providing a rich additional channel of observation on social interaction in the mirror game. In particular, besides questions about participants' overall experience of the course of the game, we asked them about special moments of the interaction - instances in which their social engagement was particularly tangible. This could be moments in which they were surprised by novel aspects of the game, unexpected behaviour of their partner, noticeable harmony between self and other, a sense of accomplishment, or associations that came up as they played the game. We did so, convinced that such moments may shed light on how we form social bonds and how we relate individual encounters with others to our wider background of (social) life.

To expand the space of possibilities for interaction while keeping the interaction dynamic relatively simple, we introduced an additional sensory feedback modality: a rich soundscape that reflects participants' directed distance when they are apart, and generates orchestra sounds in relation to their speed and position on the line when both players are in close proximity. In our experimental protocol, we included an equal number of trials with visual-only, auditory-only and audiovisual feedback. As such, we could assess the influence of the sensory environment on participants' interactive behaviour and experience.

Our analyses then focused in particular on the relationship between participants' game concurrent movement coordination and their social experience. We also considered the influence of personality differences between players as well as the interaction context. In the following, we present our findings, beginning with a more detailed description of the experimental task, setting and protocol.

**Methods**

**Participants**

20 pairs of volunteers (4 female-female pairs, 12 male-female pairs, 4 male-male pairs; mean age 26 years, range 19-34) participated in the study, receiving 10€ per hour as monetary compensation. All participants had normal or corrected to normal vision and hearing capacity, and reported no history of neurological or psychiatric illness. The current study was approved by the Ethics Committee of the Medical Association Hamburg. Participants received both written and oral instructions about the course of the experiment, and provided written informed consent prior to the recordings.

**The Sonified MirrorGame**

The experimental task we used in this study presents a simplified and sonified version of its original variant - a full body imitation task. This task is often used in theatrical contexts to practice mutual empathy and joint negotiation abilities, skills that are deemed central to group performance (Johnstone, 2012). Similar to other one-dimensional versions of the mirror game (e.g. Noy et al, 2011; Noy et al, 2015; Dahan et al, 2016, Feniger-Schal et al, 2018), our participants interacted not by full-body motion, but by using a pen (Adonit snap 2; a hard-tipped pen that runs very smoothly over monitor surfaces) to displace a virtual avatar on a tablet (iPad Air 2 WiFi; see *Figure C4A.1*). The space for movement measured 22 by one centimetres, of which only the horizontal dimension was considered in the game. Different from other mirror games, participants furthermore received sound feedback via headphones ([HD 280 PRO], Sennheiser). The sounds they heard depended on the relative position of their partner and, when close together, their joint movement along the virtual line. We considered the movement sonification a tool to expand the space of possibilities to explore while keeping the interaction dynamic between players rather simple. Similar to previous work that assessed interpersonal movement coordination under different sensory conditions (Zivotofsky et al, 2012; Bocian et al, 2018; Miyata et al, 2017; Vesper et al, 2016), manipulating the sensory feedback modality also allowed us to assess the influence of environmental (sensory feedback) conditions on participants' interaction.

Participants performed their task of producing interesting movements and/or sounds together in three different sensory feedback modalities - auditory, audiovisual and visual. That is,

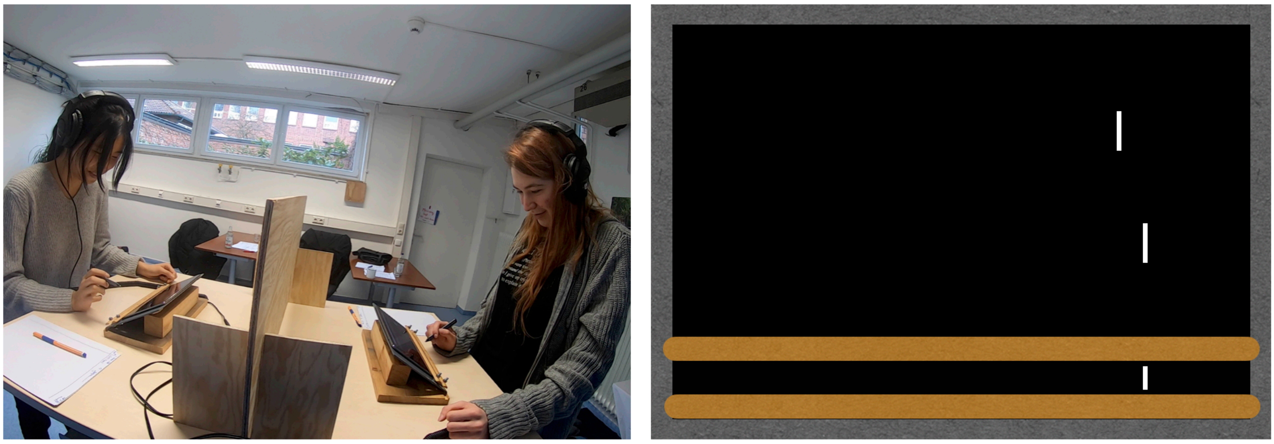


**Figure C4A.1** Setup of the Sonified MirrorGame. **(left)** Two participants engaged in the task. The wooden board allows participants' to see their partner's face, but not their hand-movements. **(right)** Tablet display during the Sonified MirrorGame. Participants control their avatar (white dash in-between the brown/ wooden bars) by sliding a touch-pen horizontally along the bottom section of the tablet. In the visual and audiovisual game conditions, participants see a copy of their own (lower top section of the tablet) and their partner's avatar (upper top section) move along the horizontal dimension of the tablet. In the audio-only condition, the top part of the tablet remains completely black.

they could either see, hear or see-and-hear the resulting interaction-dynamic with their partner. As in previous one-dimensional mirror games, participants further interacted under three different leadership instructions: they were assigned the role of the leader, follower, or told to jointly improvise movement with their partner, without clearly predefined roles. *Figure C4A.1* presents the experimental setting and tablet display during the game. *Figure C4A.2* further illustrates the auditory feedback participants receive in the auditory and audiovisual conditions when they move close together (distance < 1.25 cm): their joint horizontal displacement (mean position and speed) is translated into a 'harmonic orchestra sound'. More precisely, we play a note when the mid-point between players hits one of 60 trigger points distributed evenly across the line (inter-trigger distance 3.5 mm). The note is randomly selected from one of four chords distributed along the line, and played by either a flute (melody), a piano (accompaniment) or a string (base) instrument. The instruments and chords change as participants move along the line (see *Figure C4A.2* for an illustration). When participants move from one chord into another, the notes of the two chords are interpolated, often causing a glissando - a rapid succession of notes from higher to lower or lower to higher pitch, respectively. Like the chords, the musical qualities of the two melody, accompaniment and base instruments are interpolated at the intersections between two instrumental sets to achieve a smooth transition. Differing in style, the sets of instruments distributed along the line likely render specific kinds of (musical) behaviour more or less available, and may cause individual differences in preference. Overall, the orchestra sound algorithm renders many combinations of notes and instruments possible - it is designed to elude direct control and leads players into continuous exploration[5].

[5] You can listen to sound samples at: https://wearethefuture.net/example-runs-of-the-mirrorgame/

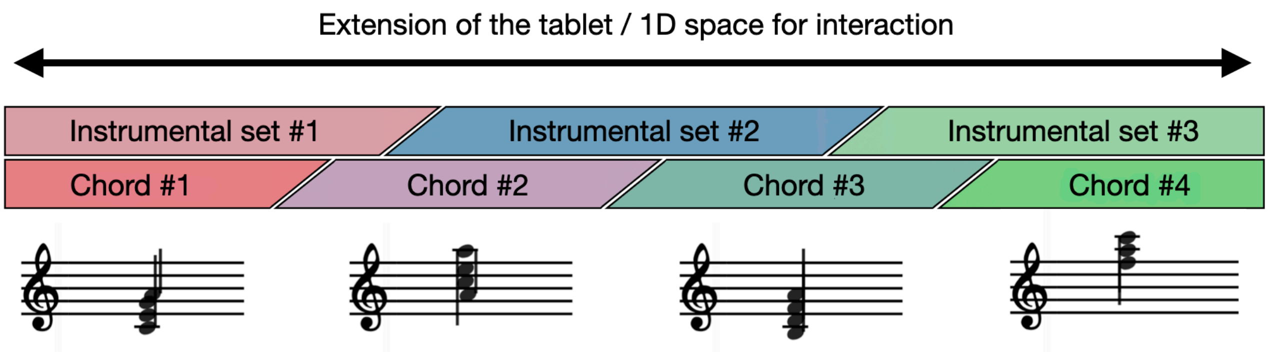



**Figure C4A.2** Illustration of the harmonic orchestra sound that participants hear when they move close to one another. The sound arises from three sets of instruments and four chords, both of which are distributed evenly along the line. The instrumental sets and chords overlap partly, that is, they are linked through linear interpolation, resulting in glissandos between the notes of the different chords when transitioning from one chord to the other, as well as linear combinations of the different instrumental qualities.

When participants' move further apart from one another, the harmonic orchestra sound fades out, and turns into a 'directed distance signal' akin to an automated parking assistant (mixing/fading between sounds at distances from 0.5 to 1.25 cm). The distance signal is communicated as a left/right panned tremolo sound (a beat, a sound with sinusoidal amplitude modulation) that reflects the directed distance to the other player. When players are relatively close to one another, the tremolo sound is of high pitch and frequency. As players move further apart, the sound decreases in pitch and frequency (from 30 to 3 Hz, that is 1800 to 180 bpm). While this sound may be perceived (and treated) solely as an error signal, it affords skilled players a means to produce sounds of a particular pitch, akin the keys on a piano. Our intention with the Sonified MirrorGame was to offer a simple and controlled (one dimensional) yet interesting space for interaction: the sound environment presents a rich additional dimension at which players need to coordinate and can improvise together. The instructions and game environment were implemented in Max/MSP, a visual programming environment for music and multimedia development (Version 8; Cycling74', 2021).

**Experimental protocol**

*Figure C4A.3* summarises the experimental protocol used in this study. We invited both participants to arrive at the institute at the same time. After welcoming and providing participants with snacks and water, we handed out written instructions. As soon as both participants had finished reading through the instructions, the experimenter verbally summarised the most important points and provided further information about the procedure. In particular, participants watched a demonstration of the harmonic orchestra as well as the directed distance sounds in relation to the movement of the avatars in the Sonified MirrorGame (first each sound separate, then both together). They also saw the magnet boards with which they completed the 'map of emotions' task, and learned about the phenomenological focus of the interviews (focus on quality and modality of experience, rather than rationalisations around the content of experience). Prior

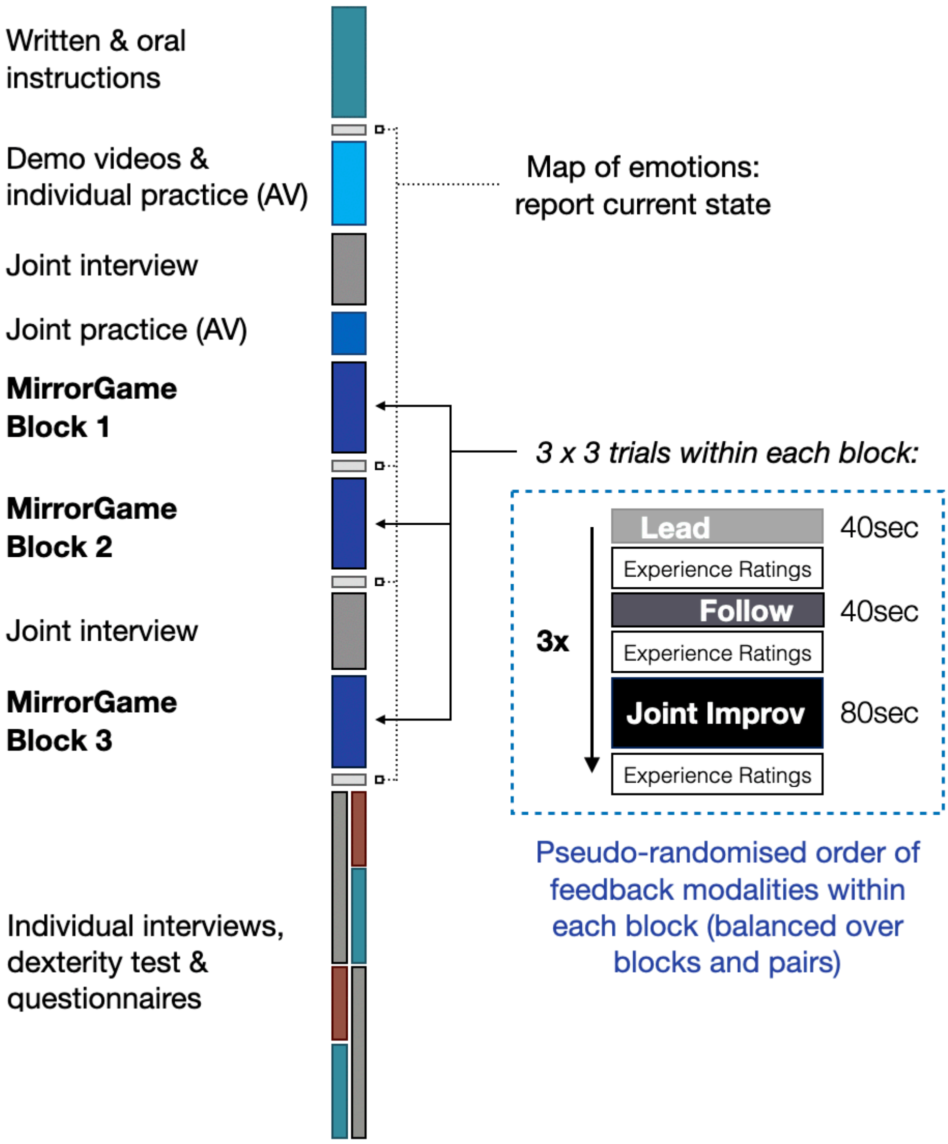



**Figure C4A.3** Experimental protocol of the Sonified MirrorGame.

to the game, each participant completed the map of emotions task and then got the chance to explore the two components of the interactive movement sonification: one minute to explore the harmonic orchestra sound with a partner-avatar that follows perfectly one's own movements, and one minute with a partner avatar that is fixed to the centre of the line to explore the distance sound. Besides familiarising participants with the soundscape, we used the subsequent joint interview as an opportunity to practice the detailed (phenomenological) report that we wanted participants to provide as part of the final individual interview. We thus asked participants to give a short summary of what they did and how they experienced this first exploration of the game environment. Next to general impressions, we asked in particular what or how they explored, and how they arrived at potential qualitative judgements (e.g. preference for one soundscape or area on the line over another). After the joint interview, we started the main part of the experiment. Participants performed each role (leading / following / jointly improvising) three times under each sensory condition (visual / audio / audio-visual), generating a total of 27 trials per pair. Lead/follow trials lasted 40 seconds, while joint improvisation trials lasted 80 seconds, amounting to equal time spent under fixed or flexible social roles. Before each trial, participants received instructions about their respective role, as well as the sensory condition of the upcoming trial. After each trial, participants answered six questions about their experience on the previous trial, and indicated whether (and if so, when) they experienced a particularly interesting social moment (*aha*-moment, experience of a feeling of discovery, special connection to one's partner, etc). See also below and *Figure C4A.4*. After each block of play, participants completed the map of emotions task. After the second block, this was followed by another joint interview in which we asked each participant to offer a broad recap of the game until now, and prompted them to describe a special moment during the interaction that took place not too long before the interview: what happened, and how did they experience it as especially interactive? Participants then returned to the final block of the game. After the game, the experimenter conducted individual interviews with the participants - meanwhile, the other participant performed a dexterity test on the game interface, and completed personality questionnaires. The dexterity test presents a scenario highly similar to the visual-only condition of the Sonified MirrorGame: participants see the partner avatar (upper dash) move in rhythmic motion left and right on the tablet (sine waves of different amplitude and frequency, centred on the midpoint of the line). Their task was to follow the movement as accurately as possible. The whole experiment lasted around two and a half hours.

**Levels of observation**

*Movement and sound recordings*: During each trial, we record participants' 1D-position along the line (192 Hz, .6 mm resolution), capture their body movement and facial expression via a camera that views them from the side ([Hero 7], GoPro, 30 fps, 1920x1440), and generate an mp3 file to capture the sound they produced (in auditory and audiovisual trials).

*Personality and prior experience*: To assess differences in personality and prior experience (in sports, music, improvisation), we asked participants to fill in the following questionnaires: a short query about relevant previous experience, a general personality test (NEO-FFI), an autistic trait questionnaire (AQ), an empathy scale (SPF-IRI), an attachment style index (ECR-R), the Tellegen sensory absorption scale (SA), as well as the Luhrmann sensory delight scale (SD). Participants generally filled in the questionnaires after they played the game, while their partner performed the dexterity test or was interviewed by the experimenter. This was to start the main part of the experiment (Sonified MirrorGame) with an 'as fresh mind as possible'. On the rare occasion of a late (>15 minutes) arrival of one of the participants, the other participant would use this time to already begin filling in the questionnaires.

*Experience ratings:* To trace participants' experience of the Sonified MirrorGame over time, we asked them to indicate their overall experience of the previous trial as well as their experience of the interaction with their partner on three scales each - *Figure C4A.4* illustrates the tablet interface for the post-trial questions. For instance, we asked participants whether they felt that the last trial was very long, or that time went by quickly. Participants used a slider / bar to provide their answer,

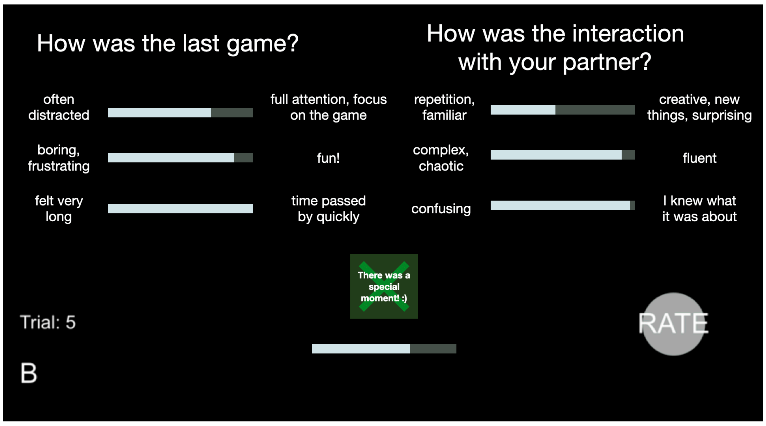



**Figure C4A.4** Post-trial experience ratings. The questions on the left side focus on participants' gaming experience in the last trial, questions on the right ask specifically about the interaction with their partner. The (optional) green button in the lower centre reports the occurrence of a 'special moment': the slider-bar below the button could be used to indicate when the moment occurred (here: towards the end of the trial).

which we recorded as a value from 0 to 127. The interface furthermore allowed participants to indicate the presence of a 'special moment' during the interaction - a moment that was particularly intense, interactively interesting or otherwise remarkable. We also pinned a sheet of paper on the table next to the tablet, which participants could use to take notes and bring with them to aid their memory in subsequent interviews.

*In-depth experience assessment*: In addition to the game-concurrent experience ratings, we performed three (joint and individual) interviews with participants to inquire about their experience of the Sonified MirrorGame in more detail. Besides asking participants about their overall experience of the game and interaction, these interviews focused in particular on 'special moments' - instances experienced as special concerning personal engagement or the interaction with one's partner. We also asked participants to complete a 'map of emotions' task at four instances during the game. Here, participants placed magnets on two metallic boards to reflect on and report their current overall state, as well as their impression of their own versus their partner's curiosity about and shared engagement in the game. For a more detailed description of the in-depth experience assessment, as well as first results from the interviews, see *Chapter 4B.*

*Measures of Movement Coordination*: We generated seven parameters to quantify the degree of coordination between players' movements (avatar position) during each trial. First, we considered participants' momentary (1) **position difference** and (2) **velocity difference**. Next, we calculated a set of five windowed lagged cross-correlation (WLCC) parameters that are based on the Spearman correlation coefficient of participants' position over short durations of time. In line with a recent validation study (Schoenherr et al, 2019), as well as our own tests with a range of parameter settings, we settled on a window size of 288 frames (1.5 seconds), a window overlap of 240 frames (1.25 seconds), a maximal lag of 230 frames (1.2 seconds), and a lag resolution of every fourth frame (0.021 seconds at 192 Hz). In other words, we created one cross-correlation matrix per trial containing 116 lags by 154 time points, under the assumptions that events last approximately 1.5 seconds, that the evolution of players' interactions can be observed at a resolution of 0.25 seconds, and that inter-player coordination does not exceed a delay of 1.2 seconds and can be observed at a resolution of 0.021 seconds. In line with Moulder and colleagues (2018), we then generated five measures of coordination. We quantified (1) overall

**synchrony** as the average WLCC coefficient across all 116 lags, generating a series of 154 synchrony values per trial (one per time step, that is for a given 1.2 second time-window). To take into account potential leading or lagging between players, we identified the lag between players' steering directions that shows the strongest correlation at each of the 154 time steps. Specifically, we picked the highest correlation coefficient above a minimum of 0.3 that was closest to simultaneous movement (0 lag). In parallel with our synchrony results, this yielded a series of 154 'winning lags' and associated correlation coefficients per trial (at 0.25 sec resolution). Wherever we could not identify such peak correlation, we set the coefficient to zero ('NaN' for the winning lag). The four additional parameters that we generated based on this series of 'peak-picked' windowed-lagged cross-correlation (ppWLCC) results therefore capture momentary coordination that lasts over short, intermittent periods of time. Here, the mean ppWLCC coefficient indicates the (2) **strength of relation** between players, independent of the lag at which it was observed. As our next parameter, the standard deviation across ppWLCC coefficients assess the (3) **variability of relation** between players. Here, higher values indicate more variability in the peak strength of relation. Next, we calculated the average ppWLCC lag to quantify the dominant (4) **time lag** between participants. This parameter ignores which participant is leading or lagging, showing only the relative time delay between players' veering directions. Finally, the tendency of players to switch between different relationships of lagging and leading, in short their (5) **switching** behaviour, was quantified as the standard deviation over ppWLCC lags.

**Statistical Analyses**

*Correlation of Experience Ratings*: To determine how well our ratings capture a shared interaction dynamic, we correlated players' ratings from each of the six questions (between-player correlation). We also correlated all ratings of a given participant, to see if answers to specific questions were more or less related (within-player correlation). We corrected for multiple comparisons with the Benjamini-Hochberg approach (Haynes, 2013), jointly controlling the false discovery rate (FDR) for all between and within-player correlations.

*Changes over Time and between Conditions (Analyses of Variance)*: To assess changes over time and between conditions of play, we calculated a repeated measures MANOVA for the entire group of movement coordination measures, as well as an ANOVA for each measure individually. In both cases, we included **block** (the first, second or third block of the game; each block consisted of 9 trials, covering all combinations of sensory and leadership conditions), **sensory feedback modality** (auditory, visual, or audiovisual) and **leadership instruction** (P1 leads, P2 leads [grouped as 'leader-follower'], or joint improvisation) as within-pairs factors (using the R package 'MANOVA.RM', Friedrich, Konietschke & Pauly, 2021). We determined p-values based on parametric bootstrapping and a (modified) ANOVA-type statistics (MATS) that can account for potential heteroscedasticity as well as singular covariance matrices, thus relaxing the assumptions of the model, and providing more reliable results with small sample sizes. We FDR corrected p-values within the multivariate as well as the entire set of univariate analyses. The latter group included the post-hoc paired comparisons calculated for all significant main and interaction effects of predictors with three levels (block: *first*, *second* & *third*; and sensory feedback modality: *audio*, *audiovisual* & *visual*). These post-hoc paired comparisons essentially consisted of an ANOVA that excluded data from one of the blocks or sensory feedback modalities, respectively.

*Predicting Experience Ratings (Linear Mixed Effects Models)*: To test whether players' fun, fluency and sense of time ratings can be predicted from their level of movement coordination, personality differences, as well as the conditions under which they played, we calculated linear mixed-effects models (using R packages 'lme4', Bates et al, 2015, and 'lmerTest', Kuznetsova, Brockhoff & Christensen, 2017). Based on between- and within-players correlation of experience, we selected three representative candidate measures for this analysis: fluency, fun and sense of time. These ratings showed the strongest correlation between the two players of a team, as well as the lowest within-player correlations. Working at the level of the pair, we aggregated data from each player into measures of *interpersonal* movement coordination, personality *differences*, as well as the *mean* experience ratings of the two players in a team. This generated 511 observations per measure (20 pairs *x* 27 time points - 29 missing values due to software errors). These choices are motivated by an interest in the interaction dynamic *between* players. In particular, we we inspired by previous work that suggests an important role for personal similarity (or difference) in sensitivity (Bahrami et al, 2010), semantic association (De Brabander & Thiers, 1984) and perspective (Bjørndahl et al, 2015) for social interactions that may be captured by personality traits. However, alternative choices may be equally informative, such as to focus on differences in experience between players, or perform analyses that consider each player (and their respective experience ratings, personality traits and movement behaviour) separately.

Each model was initiated with the following set of predictors: a random intercept for pairs, the block of play (first, second or third), two measures of game condition (leadership type and sensory modality of feedback), five measures of personality difference (from the NEO-FFI), and seven measures of movement coordination. We used a restricted maximum-likelihood estimator to fit the model and iteratively eliminated the least significant predictor until only significant predictors were left. Finally, to assess the generalisability of the final model, we performed a leave-one-out cross-validation procedure: for each pair, we correlated the real (observed) experience ratings, with the ratings predicted based on the overall winning model parameters, whose coefficients were fit based on the remaining 19 pairs' data (using R package 'rmcorr', Bakdash & Marusich, 2021; see also, Bakdash & Marusich, 2017). Higher (repeated measures) correlations indicate greater generalisability. Note that this procedure only considers fixed effects.

## Results

### Correlation of experience ratings

When comparing the six dimensions of experience that we assessed in post-trial ratings, we found most evidence for shared experience (between-players correlation) in ratings of fluency, fun and sense of time: all three correlated significantly in eight or nine of our 20 pairs, and showed an average correlation coefficient of .29 or higher (at $p < .26$). When comparing the ratings provided by a given player, we saw the strongest relation between different ratings for predictability and

| | Focus | Fun | Time | Creative | Fluency | Predict. |
|---|---|---|---|---|---|---|
| Focus | *r = .09, p = .36 (3/20, 15%)* | | | | | |
| Fun | r = .38, p = .22 20/40, 50% | ***r = .29, p = .16 8/20, 40%*** | | | | |
| Time | r = .26, p = .29 12/40, 30% | r = .26, p = .31 10/40, 25% | ***r = .29, p = .26 9/20, 45%*** | | | |
| Creative | r = .28, p = .29 18/40, 45% | **r = .45, p = .14 27/40, 67.5%** | r = .15, p = .38 10/40, 25% | *r = .13, p = .46 5/20, 25%* | | |
| Fluency | r = .21, p = .31 12/40, 30% | r = .37, p = .18 20/40, 50% | r = .07, p = .42 5/40, 12.5% | r = .15, p = .27 15/40, 27.5% | ***r = .36, p = .25 9/20, 45%*** | |
| Predict. | r = .25, p = .36 10/40, 25% | r = .37, p = .21 21/40, 52.5% | r = .07, p = .41 7/40, 17.5% | r = .16, p = .25 9/40, 22.5% | **r = .51, p = .12 28/40, 70%** | *r .13 p .46 7/20, 35%* |

**Table C4A.1** Between-pairs and within-pairs correlations of experience ratings. The darker-grey diagonal displays between-players correlation, the lower left corner displays within-players correlation. Statistics display average results for all pairs or players, respectively. The fractions additionally indicate how many pairs' or players' ratings correlated significantly.

fluency, which are correlated in 28 of 40 participants (mean coefficient of relation r = .51, mean significance level p = .12). Similarly, ratings of creativity and fun correlated in 27 participants (r = .45, p = .14). Fun ratings further appeared to relate to all other ratings except the sense of time: *Table C4A.1* presents an overview of all within and between-player correlations. Based on these results, we settled on fluency, fun and the sense of time as candidate measures to represent participants' interpersonal experience.

**Descriptive comparison of movement in auditory, audiovisual and visual play**

To give an overall impression of the movement dynamics under the three sensory feedback conditions, *Figure C4A.5* illustrates players' movement along the line during an example trial from each sensory feedback modality. As observable from these example trials, visual play was generally marked by more rapid and patterned movement, whereas auditory play involved slower movement, less patterns (recurrence) and more constant distances between players. Audiovisual play, in turn, fell in-between the two single modality feedback conditions in terms of both speed and rhythmicity (recurrence), and showed rather small position differences between players.

The slowness of movement during auditory play is likely due to a combination of difficulty to locate the other and the density of the soundscape: participants triggered a note every 3 millimetres they moved (when in close proximity to each other), and provoked intense changes in sound quality when they moved away from or towards each other (e.g. left-right panning of the sound, fade-in and -out of the orchestra sound, and changes in pitch, frequency and amount of the noise/distance sound). When they only received visual information, in turn, participants had but visual shapes and rhythms as a way of communicating or orienting. Their focus was thus likely fixed on creating 'objects' together - regular(ly increasing or decreasing) distances and speeds of moving, or characteristic moves that resembled for instance hand waving, repelling magnets or

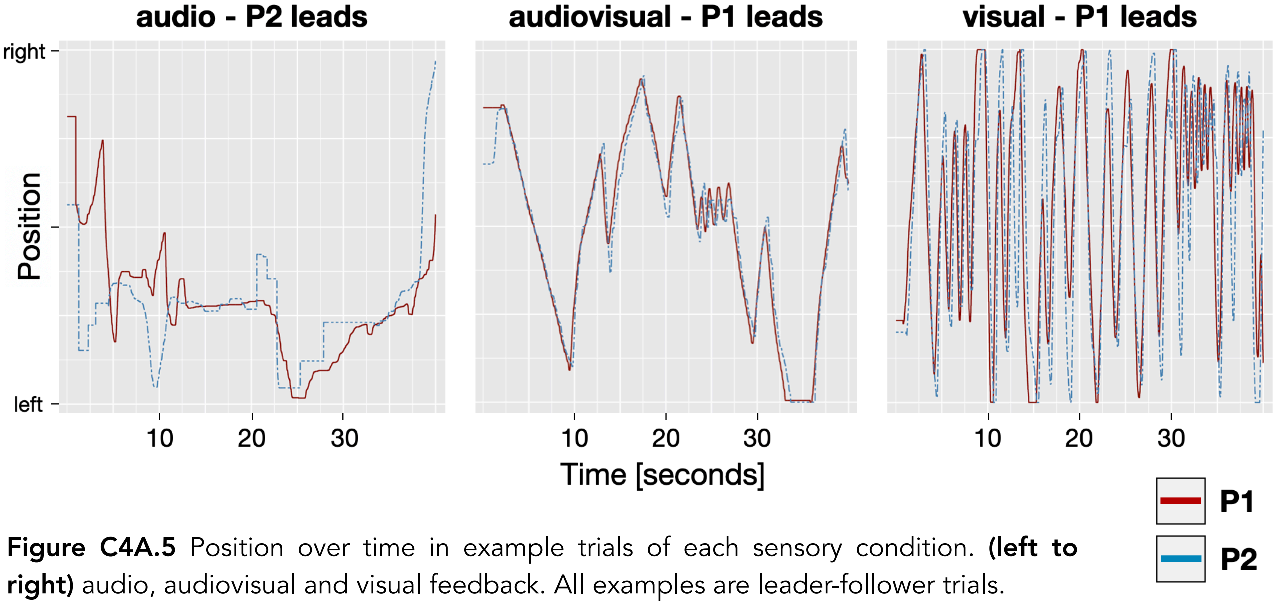



**Figure C4A.5** Position over time in example trials of each sensory condition. **(left to right)** audio, audiovisual and visual feedback. All examples are leader-follower trials.

touching somebody as if playing tag. When there was also sound, the focus of the game was yet different - while players had visual cues to orient towards each other, they still needed to handle or co-create with the rich sound environment.

**Predicting experience ratings**

We used linear mixed effects models and a backwards elimination procedure to identify significant predictors of participants' post-trial experience ratings. *Figure C4A.6A* presents an overview of our final models for the three candidate measures that we selected based on within- and between-player correlations: participants' post-trial fluency, fun and sense of time ratings. *Figure C4A.6B* further shows results from a leave-one-out cross validation that we used to assess the generalisability of our results. In *Appendix II*, *Supplementary Materials B*, we present predictor statistics for the initial and final models of fluency, fun and sense of time ratings, respectively.

Our final model of participants' **fluency** ratings includes block of play ($t = 4.047$, $p < .001$, estimate = 4.435) and synchrony ($t = 3.959$, $p < .001$, estimate = 5.742) as positive predictors, and auditory feedback (A vs V: $t = 4.336$, $p < .001$, estimate = -18.135; A vs AV: $t = 3.446$, $p = .001$, estimate = -12.986), velocity differences ($t = -4.129$, $p < .001$, estimate = -6.292), and switching ($t = -1.996$, $p = .046$, estimate = -3.379) as negative predictors. Hence, while later time and overall higher correlation between players's movements led to higher fluency ratings, receiving only auditory feedback, moving at different speeds and a more variable time lag between players reduced fluency ratings. The random intercept over pairs captured 21.5 % of the total variance, indicating a smaller relevance of pair differences compared to our results for fun and sense of time ratings. Our cross-validation procedure yielded highly significant and strong correlation between predicted and real experience ratings for repeated measures ($r = .452$, $p < .001$), as well as pair average values ($r = .486$, $p = .012$), speaking to a good generalisability of the fixed effects identified in this model.

Next, in case of players' **fun** ratings, the final set of predictors included a positive effect for synchrony ($t = 2.633$, $p = .009$, estimate = 3.306) and velocity differences ($t = 2.109$, $p = .035$,

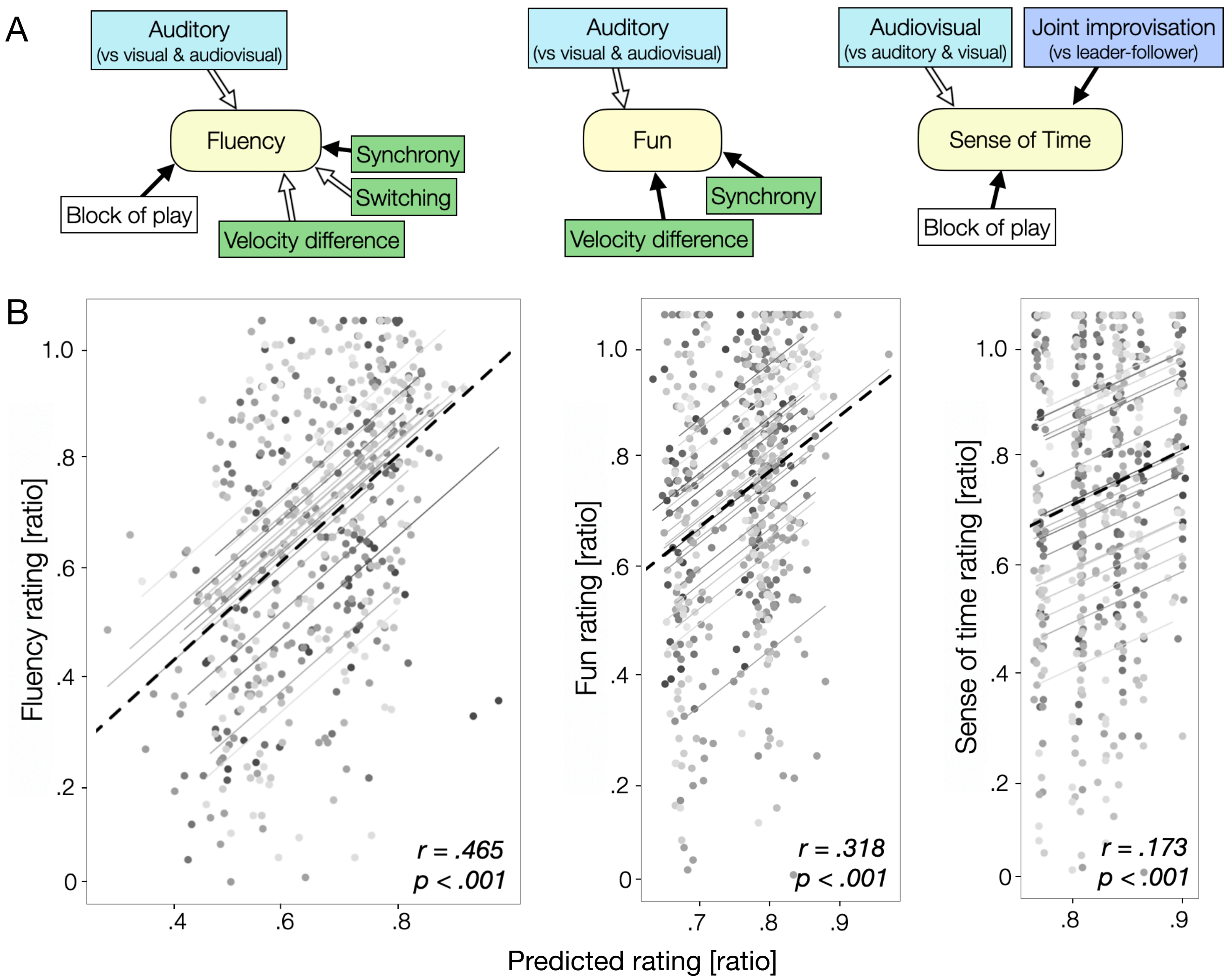



**Figure C4A.6** Linear Mixed-Effects Models of Participants' Experience Ratings. **(A)** Overview of significant predictors, that is, fixed effects in our final models of fluency, fun and sense of time ratings. Filled arrows indicate positive relations, empty arrows a negative influence (e.g. *later* block of play predicts *higher* fluency and sense of time ratings, or *higher* levels of velocity difference predict *lower* fluency but *higher* fun ratings). The colour of the predictors indicates their family membership (***blue***: game condition, ***green***: movement coordination). **(B)** Results from a leave-one-out cross-validation procedure to assess the generalisability of our final models. The dots show participants' real rating (y axis) plotted agains the rating we predicted (x axis) based on the predictors identified in our modelling procedure (square boxes in *Figure C4A.6A*). Importantly, fixed effect coefficients were estimated based on data from all pairs *but* the pair whose rating we are currently predicting (hence: leave-one-out cross validation). Lines and statistics indicate the repeated measures correlation between the 27 real and predicted post-trial ratings for each pair (solid lines) and the group average (dashed thick line).

estimate = 2.812), as well as a negative effect of auditory feedback (A vs V: t = -2.835, p = .005, estimate = -8.081; A vs AV: t = -3.855, p < .001, estimate = -10.318). In other words, while overall higher correlation between players' movements as well as moving at different speeds increased fun ratings, receiving only auditory feedback led to lower fun ratings. The random intercept over pairs captures 29.1 % of the total variance, indicating an intermediate relevance of pair difference compared to our results for fluency and sense of time ratings. Our cross-validation procedure yielded highly significant (but not as strong) correlations between predicted and real experience ratings for repeated measures (r = .318, p < .001), and pair average values (r = .484, p = .012), again speaking for the generalisability of the fixed effects identified in this model.

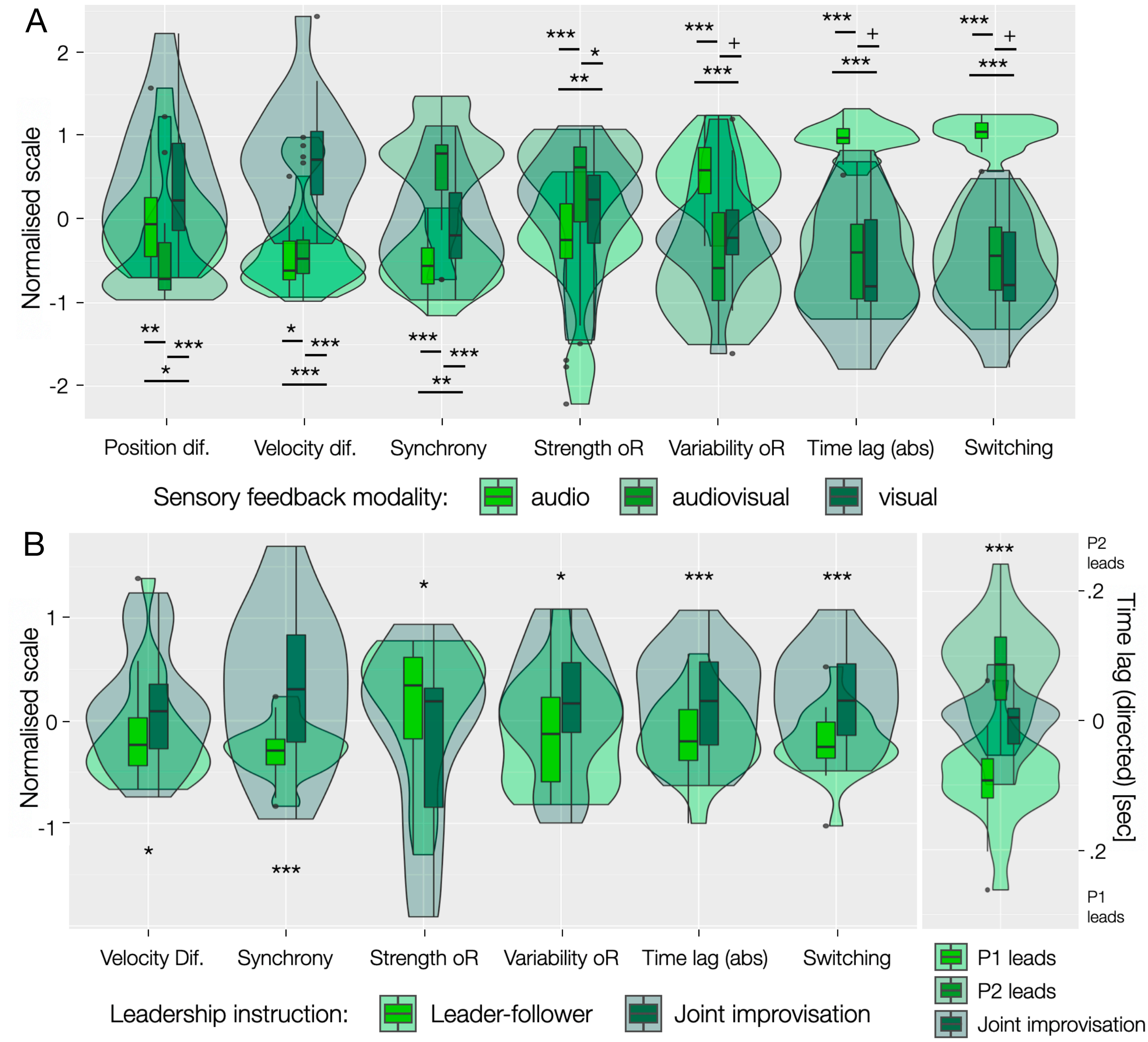
Finally, our model of players' **sense of time** ratings showed that the instruction to jointly improvise (JI vs LF: t = 13.458, p < .001, estimate = 25.484) as well as a later block of play (t = 3.879, p < .001, estimate = 3.462) increased participants' sense of time (duration) ratings, and that receiving audiovisual feedback (AV vs A/V: t = 3.624, p < .001, estimate = -6.697) led to shorter sense of time ratings. The random intercept over pairs captures 40.3 % of the total variance, indicating a high relevance of pair difference compared to our results for fluency and fun ratings. Our cross-validation procedure yielded highly significant but weaker correlations between predicted and real experience ratings for repeated measures (r = .173, p < .001), and no significant correlation for pair average values (r = .203, p = .319), speaking against the strong generalisability of the fixed effects identified in this model.

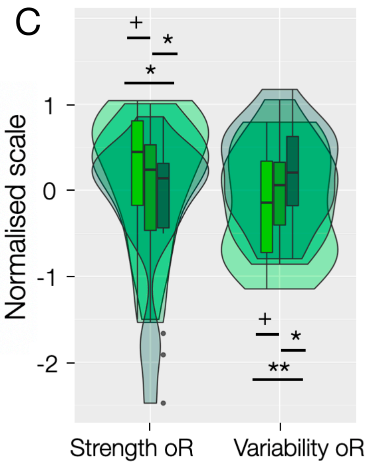
**Changes in movement coordination over time and across conditions**

We performed ANOVAs at the level of the family of movement coordination measures (multivariate analyses), as well as for individual measures of movement coordination. *Figure C4A.7* displays all significant main effects (of sensory feedback modality and leadership instruction) at the level of individual ANOVAs. *Appendix II*, *Supplementary Materials C* further illustrate all significant interaction effects and provide a table that gives a complete overview of statistics.

At the level of the family (MANOVA), we see significant main effects for both sensory feedback modality (MATS = 2283.423, p < .001) and leadership instruction (MATS = 156.036, p < .001), as well as a trend for an effect over blocks (MATS = 32.701, p = .061). We also see a significant interaction effect of feedback modality and leadership condition at the level of the family (MATS = , p < .001).

The individual measure ANOVAs confirm the finding at the level of the family: all movement coordination measures except for directed time lag show a significant main effect of **sensory feedback modality** (position difference: ATS = 16.563, p = .004; velocity difference: ATS = 70.598, p < .001; synchrony: ATS = 66.022, p < .001; strength of relation: ATS = 21.901, p < .001; stability of relation: ATS = 29.469, p < .001; absolute time lag: ATS = 74.362, p < .001; switching: ATS = 117.133, p < .001). *Visual* play involved the largest differences in position and velocity. *Audiovisual* play generated the highest levels of synchrony and strength of relation, and the lowest levels of variability (in strength of relation). Finally, *auditory* play was marked by particularly weak relations, long time lags and high levels of variability and switching (see *Figure C4A.7A*). We likewise saw main effects of **leadership instruction** for all movement coordination measures except for position difference (velocity difference: ATS = 7.294, p = .039; synchrony: ATS = 19.286, p < .001; strength of relation: ATS = 13.26, p = .014; stability of relation: ATS = 7.355, p = .040; directed time lag: ATS = 48.45, p < .001; absolute time lag: ATS = 19.315, p < .001; switching: ATS = 37.319, p < .001). Essentially, interpersonal movement is more coordinated in leader-follower trials, except for synchrony, which is higher during joint improvisation (see *Figure C4A.7B*). We found a significant **interaction effect between feedback modality and leadership instruction** in five measures of movement coordination. Jointly improvised visual play



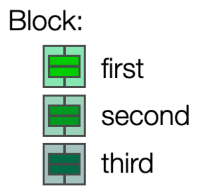




**Figure C4A.7** Significant main effects in the family of movement coordination measures. FDR corrected p values are indicated by *** ($p < .001$), ** ($p < .01$), * ($p < .05$), and + ($p < .10$). Note that the dashes below the symbols in *Figure C4A.7 A* and *C* indicate which two sensory feedback modalities or blocks are compared, respectively. All distributions are visualised as violin plots (Hintze & Nelson, 1998): besides median, interquartile range and outliers (single dots in the distribution), the shape of the violin illustrates the probability density of the data at different values. For example, the first group of violin plots in *Figure C4A.7A* illustrates that position differences are significantly lower when players receive audiovisual feedback, compared to when they only receive auditory ($p < .001$, i.e. ***) or visual feedback ($p < .01$, i.e. **). Position differences are also lower in auditory compared to visual play ($p < .05$, i.e. *) **(A)** Main effects of sensory feedback modality on measures of movement coordination presented on a normalised scale (only within-measure comparisons are meaningful!). Lines and asterisks indicate p-values of pairwise (i.e. visual vs. audiovisual, visual vs. auditory, and audiovisual vs. auditory) post-hoc comparisons for significant main effects of feedback modality. **(B)** Main effects of leadership instruction on measures of movement coordination. **(C)** Main effects of block.

was marked by particularly large position differences (ATS = 14.694, p = .004, see *Figure C4C.1A*), and jointly improvised audiovisual play by yet higher levels of synchrony (ATS = 14.131, p < .001, see *Figure C4C.1B*). On the other hand, differences between auditory and visual play in time lag (ATS = 4.703, p = .039) and switching (ATS = 13.077, p < .001) were particularly large when comparing leader-follower trials (see *Figure C4C.1 C and D*). We also saw a marked absence of directed time-lag in auditory leader-follower trials (ATS = 25.779, p < .001, see *Figure C4C.1E*). Finally, only the strength and variability of relation show a significant effect of **block** (strength of relation: ATS = 6.455, p = .039; stability of relation: ATS = 6.749, p = .030; see *Figure C4A.7C*) - interestingly, players' movements become *less* related over time: the strength of relation between players decreases, and the variability of relation increases. Beyond an overall positive influence of synchrony, this may speak to an important role of complexity and novelty for engaging social interactions. We return to this topic below.

**Discussion**

In the present study, we predicted participants' experience ratings from the conditions under which they played the Sonified MirrorGame, as well as the degree of movement coordination between them. The sensory feedback modality emerged as a key predictor of participants' experience: while auditory trials were rated as less fun and fluent, audiovisual trials felt shorter to participants. We could further relate participants' experience ratings to the level of synchrony and velocity differences between them: while synchronous movement had a positive effect on both fun and fluency ratings, velocity differences increased fun but decreased fluency. Time (later block of play), in turn, showed to increase both felt fluency and felt duration. Finally, higher amounts of switching (variability of time lags) between participants decreased their ratings of fluency.

These findings suggest several **balancing and adaptation processes** - between self and other, as well as between familiar and novel modes of play - as central to how participants engaged in the Sonified MirrorGame. In particular, both synchrony and velocity differences are positive predictors of fun, and while velocity differences and switching (both of which are higher during joint improvisation) reduced felt fluency, joint improvisation trials were usually preferred and experienced as more creative by participants (see *Chapter 4B*). These countercurrents are further confirmed in our ANOVA of game concurrent movement coordination, which revealed weaker and more variable relations between participants' movements over time, in spite of a concurrent increase in fluency ratings. Our results offer a more nuanced view on the role of (velocity) differences during social interaction (see e.g. Llobera et al, 2016). They are in line with recent empirical studies (in particular Ravreby et al, 2022) that identify both synchrony and novelty as characteristics of engaging and creative interaction. Our conclusion further agrees with theoretical work on improvisation and interaction (Holdhus et al, 2016; Hall & Stevens, 2015), which suggests a combination of structure (preparation, repertoire) and flexibility (listening, response) as key to co-creative action.

To revisit our results in more detail, we begin with the pronounced **differences** in movement coordination and experience that we observed **across sensory feedback modalities**. In particular, we consider each modality in terms of the degrees of freedom and communication tools that it affords. This is inspired by Vesper and colleagues' (2016) finding about the impact of feedback modality on interpersonal coordination, as well as participant reports: navigating the game environment and interaction with one's partner here emerged as central themes (see *Chapter 4B*).

During **visual** play, participants could either directly follow the other, or create rules and regularities that would make their behaviour predictable. This likely drew full attention to repeated patterns or characteristic signatures in the movements of the other that they could complement or match - for instance, movements of regular distance, speed or position, or movement that resembled real life objects and activities. Visual play made it easy to closely follow the other, which is reflected in the short time lags and low amounts of switching between players in visual (and audiovisual) compared to auditory trials. Interestingly, this was particularly the case for (visual) leader-follower trials: players seemed to 'follow most closely' (in time) when there was *only* visual information. Visual-only play was furthermore free from the dense soundscape that participants had to navigate (and could explore) during auditory and audiovisual play. It is plausible that players therefore felt free (and desired) to move more wild and playfully during visual play. Accordingly, we see large position differences (especially during joint improvisation) and velocity differences between players during visual trials.

When turning to sources of (dis)orientation in the **auditory** feedback modality, it is important to note that participants' movements created a diversity of sounds - motivating most participants to stay close to each other, move more slowly and carefully, and continue to adapt to one another in spite of leader-follower instructions (absence of directed time lag). When there was only auditory feedback, it was certainly more difficult for players to locate the other (or recognise patterns in their movement), depriving participants of major sources of orientation. This difficulty may explain why participants' fun and fluency ratings were lower for auditory trials, and why their position differences were larger during auditory compared to audiovisual play. The communicative challenge inherent to orienting towards one another only based on sound cues likely prompted *both* players to 'listen', follow and take initiative - regardless of their assigned role. It may have also instilled a propensity to lead in particularly follow-able ways. Due to the probabilistic nature of our sonification algorithm, auditory 'creation' (expression, communication) was furthermore less direct than in the visual domain. This likely contributed to the weaker relations, longer time lags and higher levels of variability and switching that we observe for auditory trials.

Finally, **audiovisual** play presented participants with the complete picture of the game landscape, hence the constraints and possibilities of both feedback modalities. Fittingly, we found that audiovisual play reduced players' sense of time ratings, and showed the highest level of synchrony (especially for joint improvisation trials), strength and stability of relation between players. As we elaborate on in *Chapter 4B*, participants described audiovisual play as the 'basic', 'easy' or 'natural' variant of the game. Viewed the other way around, the unusual (incomplete) character of single-modality trials may have interrupted players' experience and intensified their attention to the available feedback modality, as indeed suggested by several participant reports.

The most prominent effect of sensory feedback modality certainly concerns the striking difference in quality of attention and mode of coordination. This agrees with Vesper and colleagues' (2016) results, which demonstrate a major influence of shared visual information on how individuals coordinate towards a common goal. Our findings are also in line with Zivotofsky and colleagues (2012), who investigated synchronous walking under different sensory feedback conditions and came to assert that interpersonal synchronisation has modality-specific properties. The specific effects we see of feedback modality on movement synchronisation are less typical, in the sense that we observed the by far weakest level of coordination during auditory-only trials. The (unusual) relative importance of visual information in our scenario makes sense, however, in light of Bocian and colleagues (2018), who suggest that vision plays an important role for coordination in face-to-face scenarios and during coupled foveal vision, both of which apply in the Sonified MirrorGame. Miyata and colleagues (2017) further point out how visual information supports coordination by assimilating behaviour, thus reducing individual differences. Due to the relatively unpredictable nature of our movement sonification, this may have been particularly relevant in our task. Nonetheless, we find the highest levels of synchrony in audiovisual trials, confirming the importance of both auditory and visual cues for interpersonal movement coordination.

Beyond the already mentioned **effects of leadership instruction**, we saw enhanced synchrony - but otherwise *less* coordinated movement - in joint improvisation compared to leader-follower trials. While marking a surprising contrast (between synchrony and other measures of coordination), this result fits with Noy and colleagues' (2011) observation of increased co-confidence and creativity for joint improvisation compared to leader-follower instructions, especially when considering participants' preference for and enhanced creative experience during joint improvisation trials (see *Chapter 4B*). We also see that higher amounts of switching (a more variable time lag) between players reduced fluency ratings, and that velocity differences - while increasing fun ratings - likewise decreased ratings of fluency. We speculate that this group of effects is related to a balance between exploratory and synchronous behaviour that participants seek in order to stay engaged, and which they accomplish more successfully under the instruction to jointly improvise. We return to further discuss this topic, below.

Finally, we found that participants' sense of time ratings were higher for the (indeed longer) joint improvisation trials and that they increased **over time**. This could be related to the repetitive nature of the task. Our models further revealed an increase in fluency ratings over time - which agrees with participant descriptions of later social interaction dynamics as less effortful and more relaxed yet still interesting in new ways. In contrast with these findings, we saw that the strength of relation between players decreases over time, and that the variability of their relation increases. We interpret this as another indicator of the dual importance of synchrony (cohesion, structure, fluency, harmony) and variability (surprise, novelty, exploration, difference) for engaging social interactions - in particular, of the development of this balance over the course of an engaging interaction.

We now expand on the topic of mutual adaptation and **balancing processes as a potential organising principle** or basic framework of social engagement in the Sonified MirrorGame. Originally inspired by participants' remarks on integrating their own with their partner's ideas and preferences, as well as exploratory with harmony-seeking behaviour (see *Chapter 4B*), we find that this proposal captures our findings and matches well with recent empirical as well as theoretical work on engaged social interaction and improvisation.

Very close to our line of argumentation, a recent study compared the influence of synchrony, complexity and novelty of players' movements in a full-body mirror game on their social bonding (Ravreby et al, 2022). When modelling players' post-game social affinity ratings (how much the players liked each other), the authors found that movement complexity significantly improved the predictive power of movement synchrony, and showed that continued movement novelty differentiated remarkably well between pairs with high versus low liking ratings. Likewise speaking to our argument for a dual balancing process (self-other, synchrony-novelty), Noy and colleagues (2011) suggest that expert improvisers agree on future motions in a fine-tuned process of mutual reacting and predicting. In a follow-up study, Dahan and colleagues (2016) further highlight the ability of expert improvisers to (more quickly) leave established and form new patterns.

At a more general level, experts in the field of improvisation (Holdhus et al, 2016) and interaction analysis (Hall & Stevens, 2015) suggest that successful inter-actors generate novel and surprising dynamics ('fun') as well as harmony, mutual understanding and response ('fluency') *through* close interaction. More specifically, Holdhus and colleagues (2016) emphasise a balance between structure (preparation, repertoire and materials, planning) and flexibility (intuitive-creative responses in the moment) as essential to skilled, 'artful' improvisation. They also describe strong listening and performance components of improvisation that include the joint negotiation, setting and shifting of boundaries within which possibilities to explore are identified, accepted/rejected and continuously transformed. Finally, they point to fictional characters and plots as a key strategy for enriching improvised (inter)action. Overall, these themes fit remarkably well with participants' descriptions of a growing repertoire of patterns and modes of play, their focus on mutual adaptation and anticipation of the interaction dynamic, and the special emphasis they placed on metaphors and associations (see *Chapter 4B*). In turn, Hall and Stevens (2015), in their review of roots and applications of Interaction Analysis, highlight how material artefacts and social actors become interrelated in the effort to bring forth meaning (knowledge) across time and physical and social space. By asking 'what is there *and* interesting' (consequent for a social interaction, useful, relatable), they discuss knowledge as the shared making of 'things' connected (often explicitly, by inter-actors themselves) with "broader scales of time, place and social relationship" (p.100). Applied to the present study, this suggests that the metaphors and associations mentioned by participants might have served to integrate their activity in the Sonified MirrorGame with other routines and environments familiar to them. This may have provided orientation and a resource for creativity - a background through which their interactive experience of the Sonified MirrorGame could become tangible and meaningful. Hall and Stevens (2015) furthermore emphasise the importance of developing trusting relations or a working consensus to support interactive participation (p.78, 82): over the course of their interaction, participants may have learned to bring their individual repertoires of know-how (to build interesting social relations, sounds and movements) to bear on their shared exploration of the Sonified MirrorGame (see also, Brinck & Reddy, 2019, for an account of creative work as a dialogical process).

In summary, our findings agree with earlier work on fluent, engaging and creative interaction in their emphasis of a balance between synchrony and variability, the integration of diverse backgrounds into a domain-specific repertoire, and the development of trust - in one's own and the other's ability, as well as the possibility for interactive attunement between them.

Important **future work** remains to be done. First, we did not see effects of (differences in) general personality traits on players' experience ratings. However, earlier work with a full-body mirror game paradigm demonstrated a positive influence of secure attachment style and a negative influence of trait avoidance on 'free' (creative) behaviour (Feniger-Schal et al, 2018). Integrating the remainder of our personality scales into our analysis would therefore be in order, especially concerning the attachment style index and the sensory absorption scale. Likewise, we have yet to analyse the second half of the individual interviews (as well as all joint interviews), and did not yet include the map of emotions data. Both promise to further clarify and enrich our understanding of participants' engagement in the Sonified MirrorGame. To better integrate with earlier work, it would furthermore be important to expand our analysis to include co-confidence as an additional measure of movement coordination.

Future studies might further compare our results to outcomes with an interactive movement sonification that gives participants more control over the sounds they produce. This would be interesting in light of participants' relatively low reliance on auditory feedback to produce synchronised motion. It might also move the setting closer to the sweet spot between predictability and exploration that (as we argue) is central to engaging social interaction.

The Sonified MirrorGame clearly allowed us to study the relationship between movement coordination and social experience, and to consider the important role of contextual factors such as sensory feedback modalities and leadership instructions. In summary, we identified in particular the sensory feedback modality, but also synchrony, velocity differences between players and time (block of play) as prominent predictors of social experience. Importantly, the sensory feedback modality had a strong influence on how participants moved: slow and less coordinated with only auditory feedback, rapid and playful when only visual information was available, and the most synchronous and coordinated with audiovisual feedback. Our quantitative results integrate well with in-depth participant reports (see *Chapter 4B*), which further highlight differences in the quality of attention and mode of play, especially between the single-modality conditions. In line with closely related earlier work as well as theories of improvisation and interaction analysis, we interpret our findings as strong evidence for a dual balancing process that integrates between self and other, as well as exploratory and familiarity-seeking behaviour. Overall, our work supports an understanding of social engagement as an interactively maintained and situated process.

# CHAPTER 4B

## The Sonified MirrorGame - in-depth participant reports

### Introduction: experience assessment as a step towards co-creative research

The Sonified MirrorGame presents a multi-level investigation of the relationship between interpersonal movement coordination and social engagement in a simple but challenging joint improvisation task. To support our analyses of game concurrent experience ratings and measures of interpersonal movement coordination (presented in *Chapter 4A*), we performed more in-depth assessments of participants' experience. In particular, we asked participants about their overall state and experience at different moments throughout the experiment. More specifically, we performed joint and individual interviews, and provided a board for participants to individually reflect on and report their current state: in the 'map of emotions' task, participants positioned felt-sense qualities (such as *warm*, *cold*, *nervous*, *comfortable*, *curious*, *bored*, etc) with respect to a bodily shape, and compared themselves to their partner in terms of social engagement and playfulness. The focus of the interviews on experiential dynamics, as well as the map of emotions task further facilitate noticing aspects of and changes in one's current state. As such, they stimulate active engagement with the research process on behalf of the participants.

Below, we present these methods of experience assessment in more detail, and give an overview of first results from individual interviews performed at the end of the experiment.

### Methods

#### Participant interviews

In addition to game-concurrent experience ratings after each trial, we interviewed participants to learn more about their perspective on the MirrorGame. Specifically, we conducted joint and individual interviews with the players at three moments over the course of the experiment (see *Chapter 4A*, *Figure C4A.3* for an overview of the experimental protocol). During the interviews, we asked what it was like to play the MirrorGame, how they experienced the interaction with the game environment as well as their partner, and focused in particular on 'special moments' - instances experienced as special concerning personal engagement or the interaction with one's partner.

The first two interviews were held together with both participants and lasted around 10 minutes. The last interview was conducted individually and lasted approximately 20 minutes. We interviewed participants for the first time after their individual exploration of the sound environment. This interview was used mainly to introduce the detailed (phenomenological) interview technique, and also to invite participants' perspective and initiate a shared conversation about the MirrorGame with both participants. The second interview took place after participants had completed the second of three blocks of the game. Here, we asked participants to talk about their experience during a moment of playing the MirrorGame that was still fresh on their mind, if possible one that was special in terms of the interaction dynamic with their partner. Besides our research interest in moments during which social relations are formed, particularly tangible or connected with alternative contexts of meaning, the conversation was also intended to be an opportunity to stimulate and open up possibilities for interaction between the players. The second interview also again served as practice for an experiential report in the final interview. For one of the players, the last, individual interview took place after the final block of play. Meanwhile, the other player performed the dexterity test and completed any remaining questionnaire items. Afterwards, players swapped roles, and the second participant was interviewed. The final interview started out with open questions such as 'Which aspects of the game are still on your mind?', 'How would you recount the experience to somebody else?', and 'What was fun, what was exhausting?'. We then proceeded with more specific questions about their experience of the interaction and their partner, and the different conditions under which they played the game (roles & feedback modalities). Finally, we also inquired about participant's phenomenology of 'special moments' - outstanding interactive moments that we had also asked participants to note on a sheet beside them as they were playing the MirrorGame. Here, our interest was to learn about the experiential unfolding of a social moment that is experienced as particularly noteworthy, including similarities and differences between players.

To summarise the interview data, we performed a thematic content analysis following Elo and Kyngäs (2008) and Kuckartz (2012): in an iterative coding and refining procedure, we developed a thematic scheme that completely and unambiguously classified a quarter of the data (10 individual interviews). We then used this scheme to code the remainder of the dataset (in progress: 20/40 individual interviews coded), occasionally merging or refining codes to accommodate novel content and avoid very small categories.

### Map of emotions task

At four instances during the experiment, we furthermore asked participants to complete the 'map of emotions' task. Here, participants were presented with two metallic boards, one on which they could place magnets labeled with felt-sense qualities (fun, bored, interesting, warm, cold, curious, satisfied, etc) relative to a human shape, and another board on which they were asked to position a magnet for themselves and their partner along two axes: from tired to playful, and from isolated to connected. We recorded their answers by taking a photograph of their placement - *Figure*

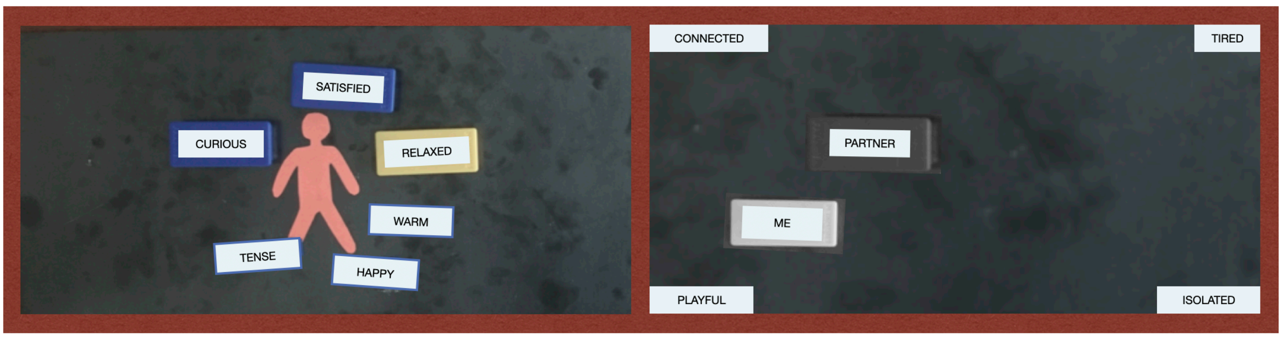



**Figure C4B.1** Map-of-Emotions task. **(left)** Participants rate their current state by selecting from a pool of available emotion words and placing them around the red human shape present on the board. **(right)** Participants rate their own and their partner's state along two axes (connected--isolated, playful--tired).

*C4B.1* displays an example answer provided by one of the participants. This way of assessing participants' overall state in relation to their partner was inspired by a similar task used in Himberg and colleagues (2018).

**Results**

**Themes mentioned in individual post-game interviews** (*20 of 40 individual interviews coded)*
In the Sonified MirrorGame, participants discovered a diversity of opportunities to learn about themselves and their partner. Our thematic content analysis of post-game individual interviews revealed six major themes: (1) *overall impressions*, including changes over time, associations and metaphors, suggestions for improvement (of the MirrorGame) and comments on their sense of time; (2) *orienting / figuring it out*, in particular how to interact with the partner (participants differentiated modes of play, voiced concerns around [not] following, commented on the personal nature of the interaction, and felt eager/pressured to come up with interesting ideas); (3) *emotions* - further grouped into positive, negative, and those related to special interactive moments; (4) *sensory feedback modality*, that is comments about the (different) nature of visual, audiovisual and auditory play; (5) *leadership instruction* (lead vs. follow vs. jointly improvise); and (6) *general social preferences* - participants' answers to our questions about situations in which they enjoy interacting with, leading or following others. All clusters reflect one or several of the questions that we asked in the individual interview - see *Appendix II*, *Supplementary Materials A*, for an overview of all interview questions. Below, *Figure C4B.2* presents the sub-categories that make up the largest two clusters: 'emotions', as well as 'orienting / figuring it out'. In *Appendix II*, *Supplementary Materials D*, we further provide example quotes from all codes in these two clusters.

Participants' answers clearly demonstrated the social nature of the MirrorGame: all participants reported a social rather than computer (tablet) or gaming-oriented focus. When asked to describe the essence of the game, they furthermore gave examples that emphasise listening and collaboration, mutual adaptation, finding common ground and resolving a situation together. Early in the game, participants were concerned with figuring out the game environment. They experienced a need to orient themselves in the different leadership instructions and sensory feedback modalities of the game, in particular the interactive movement sonification. After that, they were mainly focused on understanding and anticipating the actions and preferences of their partner, and coming up with interesting and creative ideas for the game. Remarkably, the two often coincided: players sought *shared* possibilities for action - modes of play and patterns of movement that both could recognise and enjoy. Thus, they tried to propose follow-able suggestions, while making use of creative impulses and opportunities to adapt to each other. Though the task became repetitive over time and several players reported a lack of new ideas towards the end, many players express sustained interest in coordinating and exchanging with their partner, and therefore in the game. Of note, several participants remark on a better quality of interaction in the last period of the game - less effortful and more relaxed, yet still interesting in a new way.

A

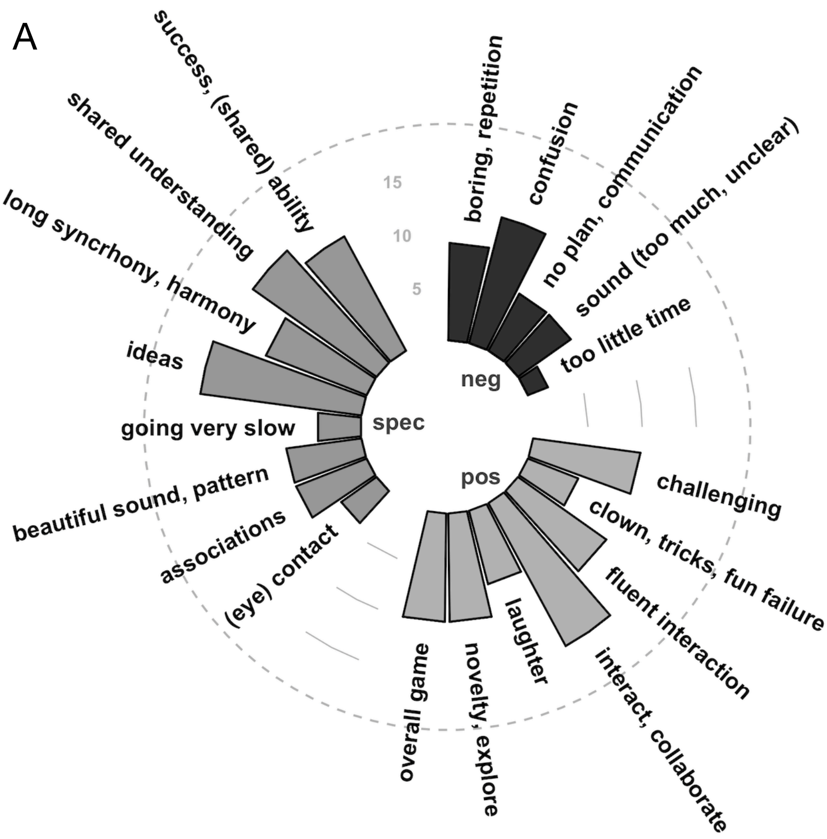
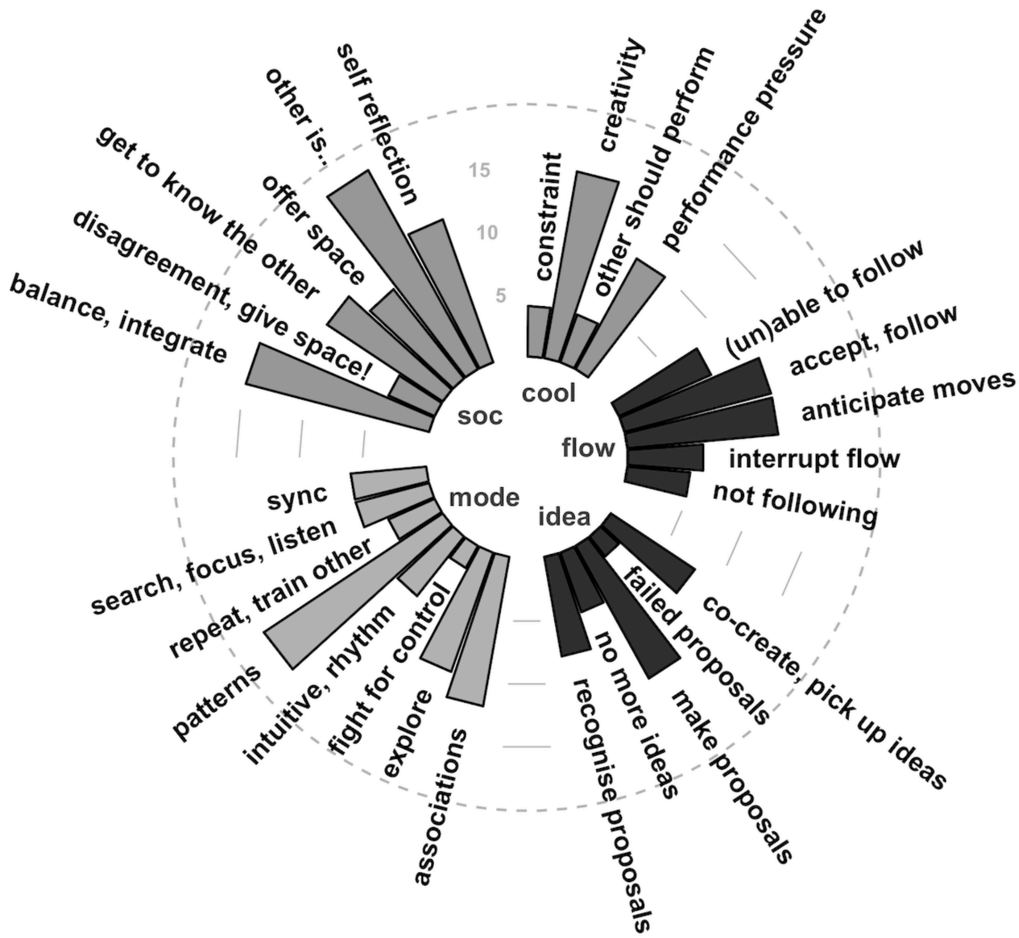



**Figure C4B.2** Largest two clusters from the thematic content analysis of individual, post-game interviews. Nearly all participants (>= 17 of 20) mention all main categories in both clusters. The dashed perimeter of the radial histogram indicates the full number of (coded) participants. **(A)** Sub-categories of the 'emotions' cluster, with main categories: *1) neg* - negative emotion, *2) pos* - positive emotion, *3) spec* - the experience of a special moment of interaction. **(B)** Sub-categories of the 'orienting - figuring it out' cluster, with main categories: *1) cool* - the motivation to do interesting things, *2) flow* - comments around (not) following and follow-ability, *3) idea* - remarks on making and recognising proposals, *4) mode* - descriptions of different modes of playing, and *5) soc* - comments about personal and social dynamics.

B



Overall, the topics of **shared understanding** and **creativity** emerged as central: shared and in particular new ideas, mutual adaptation and other signs of successful collaboration make up the largest sub-categories of both the 'positive emotion / fun' and the 'special moments' cluster. We would like to give special attention to the topic of '**balancing**', which - though not explicitly asked for - was mentioned by the great majority of participants in the interviews. In our thematic content analysis, we grouped comments on balancing self and other, with comments on achieving a balance between creativity and follow-ability (smooth interaction). Participants refer to this dual process of balancing by pointing out that "*there was this question about creativity - so, you tried to do something new - but, you wouldn't want to confuse your partner either - I think we did this quite well*" (Pa22P2), "*he responds to my stuff, the other way around as well*", (Pa22P1), or, "*I felt that there was this kind of tension - to always find the balance. When I was like this, he was like that. So, if I was very logical, then he would be rather intuitive, and vice versa. And when that was the new logic, then, back to analytical mode, focusing on order*", (Pa25P2). Whether leading, following or jointly improvising, participants needed to solve the task together, and experienced getting to know and **understand each other**, finding new patterns, modes of play and real-life associations to what they were doing as rewarding. They also remarked very positively on moments in which the other would understand and take up their proposals. Orienting, anticipating what happens next, and noticing when it is time to drop the current mode of play formed a central part of how participants played the MirrorGame. In terms of elements that supported their creativity, participants mention **freedom from making mistakes and (embodied) intuition**: "*it's several things - feeling free from.. 'I don't have to be right/correct'.. and because of that, I was more in my body - the visuals, the movements of the dashes, as if that was two balls inside me - sensing it like that, more haptic, plastic*" (Pa9P1), or, "*this was like during my improvisation class, when I could trust the group - so I could feel that yeah, she's good at this, she will follow me and I just did it, didn't really hesitate, and then she also followed that and the next trial we had like a practice moment, that was really cool*", (Pa26P2), or, "*I think this.. darkness… when I made a mistake - it was not so 'in your face, in front of me' .. as if I had closed my eyes, I could really rely on my musical intuition to guide me, give up control. With visuals, that didn't work, something was reactivated too much somehow..*", (Pa21P1). Likewise important were **associations**, both as a strategy to find patterns and interesting ideas ("*it was often like catching, playing hide and seek (visual)*", Pa21P1; "*I tried to slide left & right, and then gradually moved with the rhythm of basketball - for example, sudden stops*", Pa19P1), as well as a way to recognise special moments ("*I felt there was a conscious waving motion, human-like, even though we were in the audio only condition*", Pa12P2; "*those deep tones, like a funeral… or once when I was following, it reminded me of a bus honking because of a construction cite - and when I would move away, there was this dong-dong-dong sound, like a compressed air gun, so the association became even stronger - oh lord, I thought, haha*", Pa21P2).

Participants experienced the three **sensory feedback modalities**, especially visual and auditory play, as markedly different. They reported that distinct aspects of their experience were enhanced, that the focus of their attention changed - that their thoughts and modes of play were different. In general, participants found it much easier to orient when they received visual feedback. In absence of the (dense) soundscape, they moved faster, felt freer to move further apart and overall more boisterous and playful. Visual play was furthermore marked by patterns - repertoires of recurrent movement sequences that players established over the course of their interaction. Auditory play was in turn described as more difficult and demanding of focus, as well as usually slower: participants were more careful in their leading and following, but also experienced stronger rewards when they collaborated successfully. Most participants described the orchestra sound as too unpredictable - they would have preferred more direct control over the sounds, so as to deliberately create tunes and melodies. Participants differed, however, in their preferred sensory feedback modality and mode of play: while some participants felt constrained in their creativity in either of the single-modality conditions ("*only visual is the most boring*", Pa25P1; "*with audio only, you can't play because you have to stay together or else it is irritating*", Pa13P1), others experienced them as a source of inspiration: "*when one modality is gone, the other is enhanced - it was super interesting to observe that*" (Pa16P1), or, "*my thoughts were really influenced by the different conditions*" (Pa21P1). Participants who enjoyed auditory play for example remark that they were "*most focused in the auditory only condition - it was most exciting!*" (Pa12P2), or that their *"attention was really somewhere else, somewhere totally different. Not fixed on the board, like with the visual"* (Pa22P1), and how they *"felt more free from making mistakes.. as if I had closed my eyes, I could really rely on my musical intuition to guide me, give up control. With visuals, that didn't work, something was reactivated too much somehow.."* (Pa21P1). In turn, other participants were focused on visual play: "*I never expected so much communication and fun to be possible through this simple interaction with a dash!*" (Pa13P2), "*I think my favourite trial was when we were just playing around like that, like making silly jokes with the dashes!*" (Pa13P1), or "*with only visual, it didn't really feel like this is someone just in front of me, but I also imagined someone, somewhere else, that I really don't know, but, we don't care, we're only focusing on the creative side. Yeah, and then, that was really cool."* (Pa26P2). Likewise, some players relied primarily on visual information during audiovisual play, while others were more focused on the auditory feedback.

Concerning **leadership instructions**, most participants preferred to jointly improvise. They associated joint improvisation with flexibility to move between making, accepting and modifying existing proposals, and the possibility to express creatively together. Some players reported that they were overwhelmed with the instruction to lead, which put them under pressure to perform, and more relaxed in the role of the follower, where they knew what to do. Other participants enjoyed leading, in particular the challenge to trick their partner or see their ideas realised by them. Yet other players were bored with following, and quickly resorted to break repetitive routines by switching to other, or inventing entirely new patterns and modes of play: "*the rhythm was too much 'ping-pong', back and forth, cliche - better to have less regularity*" (Pa16P1), or, "*following can also be like this? Repeatedly crossing, finding a rhythm, playing a game - doing something surprising, not so much planned. Strict following would have been very focused - this was more intuitive*" (Pa9P1). Overall, regardless of leadership instruction, players wanted to propose follow-able suggestions, adapt to each other, anticipate the interaction dynamic and recognise opportunities for creative moves to maintain an interesting interaction dynamic.

Finally, when asked to describe pleasant social interactions more generally, participants named characteristics such as balanced, mutually aware, receptive and active; trusting, affirming and expressive; familiarity, shared humour and interests; but also genuine contribution, welcoming of differences and flexibility in exchanging or sharing roles.

**Discussion**

Our analysis of post-game individual interviews confirmed the social - even personal and transformative - nature of participants' engagement in the Sonified MirrorGame.

Overall, the topics of **shared understanding and creativity** emerged as central themes: shared and in particular new ideas, mutual adaptation and other signs of successful collaboration made up the largest sub-categories of both 'positive emotions / fun' and 'special moments'. Relatedly, the topic of **balancing** - though not explicitly prompted through our questions in the interviews - was mentioned by the majority of participants. More specifically, participants often desired a balance between their own and the other's ideas and preferences, as well as between creative and follow-able behaviour, so as to accomplish smooth interactions that involve harmony and exploration. Remarkably, the two often coincided: players sought *shared and interesting* possibilities for action - modes of play and patterns of movement that both could recognise and enjoy. Thus, players noticed the boundaries of the interaction, but made use of creative impulses and opportunities to adapt to one another.

Fittingly, players further talked about their motivation to **learn about the other**, listen to and recognise each other's proposals, and seek common ground. They also emphasise building a **shared repertoire** - patterns, modes of play or ways of moving that allowed them to produce sounds and coordinated movement together.

A common resource for finding patterns were simple regularities (e.g. taking turns at regular or regularly changing intervals), as well as more complex metaphors and associations (e.g. playing hide and seek, visiting each other, behaving like magnets repelling off of each other). Many participants further talk about pressure to perform and be creative, or in other words the need to feel free from making mistakes, be comfortable with the lack of a clear frame and ready to explore intuitively. Some, in this respect, mention an embodied component of more intuitive exploration, in particular in the auditory only condition.

With regard to the **sensory feedback modality**, participants reported striking differences in attention and mode of play between visual, audiovisual and auditory play. Though participants differed in their preference for a particular feedback modality, most commented about the surprisingly playful nature of interacting with only visual feedback. Concerning auditory play, participants remarked on a need to slow down and interact more carefully, as well as overall more intuitive strategies to know how and where to move next. Whether during auditory or audiovisual play, participants comments also indicated awareness of each other's preference for certain instruments, causing them to spend more time in respective areas along the line. Finally, audiovisual play was often described as the complete or basic version of the game - the easiest game condition. Participants' largely distinct experience of the game under the different feedback modalities fit with the results from our models of game-concurrent experience ratings, where the sensory feedback modality emerged as a primary predictor of fluency, fun and sense of time ratings. Likewise, they speak to the highly different ways of moving that we saw in both raw movement traces as well as our ANOVA of movement coordination measures.

Regarding the leadership instruction, participants expressed a preference for and enhanced creative experience in **joint improvisation** trials. Again, these comments integrate well with the results presented in *Chapter 3A*. Jointly improvised motion (which led to markedly higher levels of synchrony, but otherwise apparently lower levels of coordination) indeed appears to better accomplish the important balance between synchronous and novel behaviour. The models of game-concurrent experience ratings further indicated a positive influence of synchrony (which is higher in joint improvisation) on fun and fluency ratings.

Though the task became repetitive over time and several players reported a lack of ideas towards the end of the game, many players express sustained interest in coordinating and exchanging with their partner, and therefore in the Sonified MirrorGame. Of note, several players remark on a better quality of interaction in the later part of the game - less effortful and more relaxed, yet interesting in a new way.

In the previous chapters, I presented my work on *social sensorimotor contingencies*: dynamics of mutual sensitivity and response that bind us in sustained relations with other individuals and our environment, and provide the foundation to our social cognitive skills and experience.

I began by motivating and situating my approach amongst embodied and enactive theories of cognition. In particular, I highlighted the concepts of participatory sense-making and sensorimotor contingencies (*Chapter 1*), which the work presented in *Chapter 2* expanded on by introducing social sensorimotor contingencies as a comprehensive framework to study common dynamics across the multiple levels of influence on social behaviour and experience. The key insight from this theoretical work is that **cognitive abilities** can meaningfully be understood and modelled as situated and relational capacities - intertwined so closely with our body in motivated interaction with the world that they are best understood **as a form of situated practice**. In particular, the concept of social sensorimotor contingencies emphasises shared rhythms or patterns in our perception and action as a central locus or hub of social cognitive organisation. Hence, in my experimental work, I looked for traces of social cognitive sense-making at the level of interpersonal movement dynamics. In two laboratory paradigms, participants played interactive games: the BallGame and the Sonified MirrorGame. Both involved continuous sensorimotor coordination, prioritised engagement on behalf of the participants (including in-depth assessment thereof), and used innovative methods to integrate results from several levels of observation. In particular, I specified measurable relations between interpersonal movement coordination and social experience that considered the larger interaction context as well as longer-term manifestations of personal experience (in interview reports and personality questionnaires).

In the work on the **BallGame** (*Chapter 3*), we saw that a higher number of targets collected and greater variability in the strength of relation between participants' steering actions persistently emerged as significant predictors of enhanced social experience (see *Figure C5.1*). While

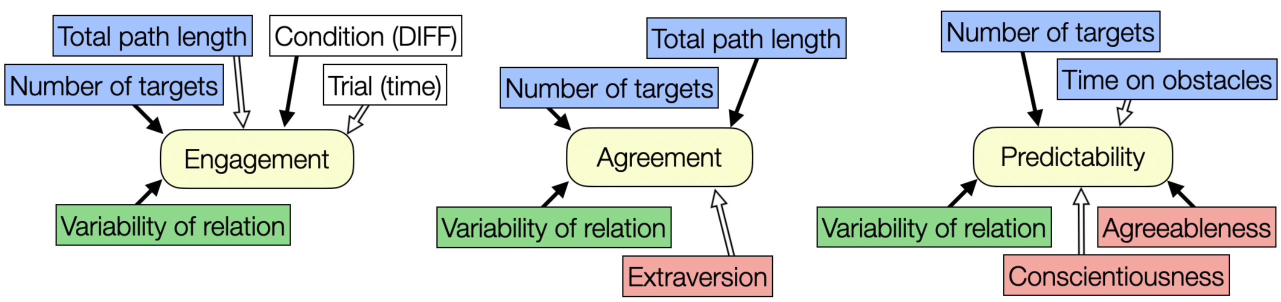



**Figure C5.1** Results from a mixed-effects modelling approach to predict participants' experience ratings in the BallGame. Empty arrows indicate negative influence (e.g. later time led to lower engagement ratings, and extraversion differences decreased agreement ratings), filled arrows indicate positive influence (e.g. being in the joint play DIFF condition led to higher engagement ratings). **Blue**: measures that capture participants' gaming behaviour. **Green**: measures of interpersonal movement coordination. **Red**: measures that capture differences between players in their personality trait scores.

moments of reward (collecting a target) are an intuitive predictor of enhanced experience (see also, Krath et al., 2021), the positive role of variability in interpersonal coordination presents a less common finding. We interpret this finding as a dual **importance of both synchronous *and variable* behaviour for social engagement**. This interpretation is also supported by the mixed picture of findings we identified across our two joint play conditions. When players saw exactly the same six of nine obstacles (and three remained invisible to both; *joint play SAME*), they collected more targets but also spent more time on obstacle regions. Measures of undirected coordination (synchrony, strength of relation, mutual information) were furthermore higher and showed a stronger increase over block steps (3-4 minutes of play) in joint play SAME. However, undirected coordination increased more strongly from the first to the second session (~25 minutes of play) for periods in which players had in part complementary views of the game landscape (and no obstacle remained invisible to both; *joint play DIFF*). Finally, in models of game concurrent experience ratings, engagement was enhanced in the complementary view (joint play DIFF; see *Figure C5.1, left*). Our models further revealed both positive and negative influences of personality differences on players' experience ratings: while teams of players with similar levels of trait extraversion and conscientiousness showed increased agreement and predictability ratings (possibly mediated by similarity in game-strategic preferences), between-player differences in trait agreeableness led to higher predictability ratings (possibly due to players' propensity to adopt complementary, leader-follower roles). Overall, these findings suggest that successful and engaging interactions may benefit from both shared (synchronous) as well as complementary information (variability, differences). In line with this, recent empirical work on musical ensemble performance (Proksch et al, 2022) identified recurrence, stability *and variability* as significant contributors to coordinated performance. Likewise, theories of participatory sense making (De Jaegher, 2007) and joint action (Sebanz et al, 2006) emphasise the role of variability and integration of differences for engaging social interactions. Finally, a prominent account of cognitive and brain function - predictive coding (see e.g. Clark, 2016) - puts the continuous development of reliable hypotheses *through effective tests and challenges* (such as provided by variability and differences) centre stage. For a complete overview of the modelling and ANOVA results, as well as how they make sense in light of an important balance between synchrony and variability, see *Chapter 3A*.

To complement these comprehensive analyses of game concurrent observations of behaviour and experience, we identified and followed up on key themes mentioned in post-game interviews (see *Chapter 3B*). For example, prompted by participants' frequent mention of objects in the game environment, we showed that the **strength of relation** between their steering movements was **higher around target collection events and** when the ball was closest to **obstacles that both players could see**. This result confirms our finding of a positive impact of shared visibility (joint play SAME) on interpersonal movement coordination. Remarks about being occupied with social understanding in the early trial, to focus on steering performance as the trial progressed, further led us to reveal **striking within-trial shifts** in our game concurrent observations: from the first to the second third of a trial, the number of targets collected and the path length traveled by the ball increased. Obstacle time and coordination (synchrony, strength of relation), in turn, only improved significantly towards the final trial third of a trial. Noteworthy about these marked within trial dynamics is in particular the discrepancy between the evolution of coordination (high during the late trial) and reports of social experience (most engaged early during the trial). Finally, the discrepancy between players' experience of the final block of individual play (as either a relief or a burden) pointed to **within-group differences at the shift from joint to individual play**. Indeed, we could trace these differences in an effect of interpersonal coordination on performance: while strongly coordinated players' (high) performance drops as they move from joint to individual play, less coordinated pairs' (overall lower) performance increases.

In future work, we should address the **suggested links between personality traits, strategic preferences and measures of interpersonal movement coordination**. In initial analyses, we could show that within-team agreeableness differences do relate to the absolute time lag between players - it would be important to further investigate and elucidate the beneficial effect these personality-differences showed to have on predictability ratings. Likewise, we should assess whether players who talked excitedly about risk and challenge indeed showed higher trait extraversion, and whether players who voiced a preference for repetition and exploiting a once identified path scored higher on trait conscientiousness. Another follow-up analysis concerns the differences we identified between coordinated and uncoordinated pairs at the transition from joint to individual play: can we trace the effect in our experience ratings and show, for example, that players from uncoordinated pairs not only collect more targets but **also experience a surge in engagement** during the final block of individual play? Beyond these immediate and concrete steps, our dataset holds significant untapped potential: the analyses of game concurrent eye tracking and brain activity recordings has yet to be integrated with the remainder of our findings.

Future research could then investigate the role of variation (the combination of synchrony and variability) that appears central to fluent and engaging social interactions. Besides using available methods (ratings, interviews) to learn about the role of predictability and variation in participants' social experience, it will be important to develop approaches better suited to **capture changes over time** (see for example Noy et al's, 2015, use of a continuous sliding scale for participants to rate a parameter of experience as they watch recordings of recent interactions), as well as the **influence of interpersonal dynamics and other contextual factors** (see Kalaydjian et al, *in press*, who trace the emergence of simple proto games in interactive gestures that suggest, recognise and confirm possible rules or behaviours; Kimmel et al's, 2018, detailed phenomenological records of embodied and interpersonal dynamics during the modern dance form contact improvisation; as well as Hall & Stevens', 2015, suggestions for the analysis of verbal and embodied expressions as instruments for co-creative meaning-making - driven by personal motivation, supported by material artefacts and constrained by the situation). The integration of such data with quantitative physiological and behavioural recording techniques presents a highly promising avenue for developing methods, hypotheses and theories sensitive to the intricate and dynamic relations between relevant levels of organisation. Yet another approach could be to **use experimental design to facilitate a combination of predictability and surprise** that appears central to engaged successful interaction: for example through communication that invites engagement as equals, or experimental protocols and spaces that offer opportunities to coordinate and exchange but remain curious towards the questions and resources brought in by participants.

Results from the **Sonified MirrorGame** (*Chapter 4*), in turn, identified the **sensory feedback modality** as the strongest influence on participants' experience and interactive movement dynamics. Players reportedly and evidently moved more playfully - at different speeds and furthest away from each other - when there was only visual feedback. When they oriented by auditory cues only, they moved slower, more careful and intuitive - they showed the smallest velocity differences, but also lowest levels of synchrony, weak and more lagged and variable relations. Finally, players experienced the combined, audiovisual feedback modality as the natural, complete, basic or easy variant. In line with these reports, audiovisual play showed the highest levels of synchrony, and the strongest as well as the least variable relations between players' movements. As observable from *Figure 5C.2*, the sensory feedback modality also consistently emerged as a predictor of participants' experience ratings: fluency and fun ratings were lower during auditory play, likely due to the challenging (relatively unpredictable) nature of the interactive movement sonification. Participants' sense of time was further reduced during audiovisual play, which fits with reports about this condition as the complete or natural variant of the task. The prominent influence of feedback modality on interpersonal coordination makes sense in light of work on coordinated reaching and walking, which revealed a strong influence of the interpersonal feedback condition on how individuals coordinate (Vesper et al, 2016; Zivotofsky et al 2012). Perhaps unusual is our finding of lower levels of coordination during auditory-only feedback, which indicates a high reliance on visual information in the Sonified MirrorGame. This makes sense, however, when considering that participants stood face to face, looked directly at

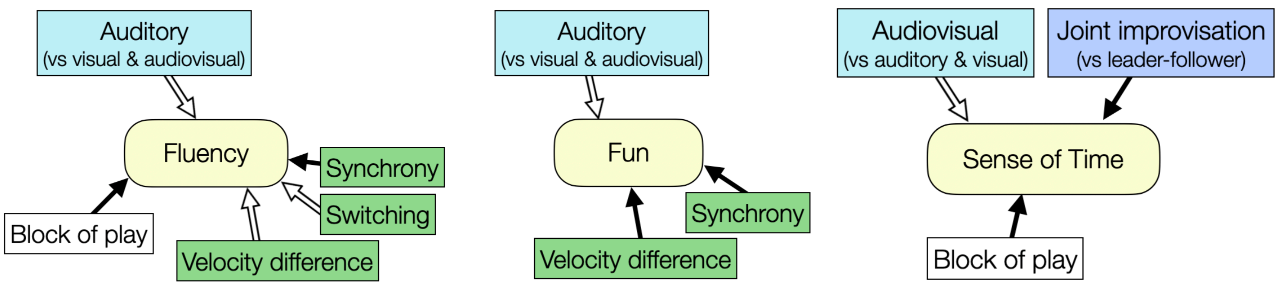



**Figure C5.2** Results from mixed-effects models that capture the influence of game concurrent observations on participants' experience ratings in the Sonified MirrorGame. Empty arrows indicate negative influence (e.g. higher velocity differences or receiving only auditory feedback reduced fluency ratings), filled arrows indicate positive influence (e.g. later blocks of play were associated with higher fluency ratings). **Green**: measures of interpersonal movement coordination. **Light blue**: sensory feedback modality. **Dark blue**: leadership instruction.

the small virtual avatar they were moving to coordinate with their partner (note the emphasis that Bocian et al, 2018, place on foveal vision as well as visual information more generally in face-to-face scenarios), and received auditory feedback that was relatively complex and probabilistic (see also Miyata et al, 2017, who argue that shared visual information assimilates behaviour and may thus serve to reduce individual differences).

Next to the sensory feedback modality, the level of synchrony and velocity differences between players, as well as the time they had played together, were additional predictors of participants' experience ratings in two of our three models (see *Figure C5.2* as well as *Chapter 4A*). Note in particular that while velocity differences increased fun ratings, they decreased ratings of fluency. In our ANOVA, we further saw that synchrony was enhanced during jointly improvised play, whereas all other measures indicated higher levels of coordination during leader-follower trials. Together with participants' preference for and enhanced creative experience during joint improvisation trials, we interpret this group of findings as evidence for **a balance between predictable** (e.g. synchronous) **and exploratory behaviour** (e.g. velocity differences), **as well as between one's own and the partner's preferences**, which participants indeed frequently touched on in the interviews. This view corresponds with closely related recent work that used a full-body mirror game to trace the development of social affinity at the level of interpersonal movement dynamics (Ravreby et al, 2022). Here, the authors highlight both interpersonal synchrony as well as movement complexity and novelty as key predictors of social bonding. Earlier work with one-dimensional mirror games further identified ongoing interpersonal attunement (Noy et al, 2011) as well as departure from established patterns (Dahan et al, 2016) as markers of expert joint improvisation. This fits with our analysis of participant interviews (see *Chapter 4B*), which illustrates participants' growing repertoire of patterns and modes of play, highlights their attempts to mutually adapt and anticipate the interaction dynamic, and places special emphasis on metaphors and associations that come to mind during the game. In line with this, theoretical accounts of improvisation and interaction analysis (Holdhus et al, 2016; Hall & Stevens, 2015) describe both structural (preparation, repertoire, performance) and flexible elements (listening, intuitive-creative response) as essential, and again highlight the *joint* negotiation, setting and shifting of boundaries within which possible ways of interacting are identified and continuously transformed. They also suggest borrowing from fictional characters and integration with one's diverse life backgrounds as a key strategy to enrich improvised (inter)action.

In summary, together with earlier work on fluent, engaging and creative interaction (note in particular Dahan et al, 2016; Walton et al, 2018; Ravreby et al, 2022; Proksch et al, 2022), our findings highlight a balance between synchrony and variation, the integration of individual ideas and backgrounds of experience into a domain-specific repertoire, and a resulting sense of orientation and possibility - through one's own and the other's ability, as well as interactive attunement between them. For a complete discussion of quantitative and qualitative results from the Sonified MirrorGame, see *Chapters 4A* and *4B*, respectively.

Important parts of the analysis remain to be done. First, the map of emotions data, remainder of participant interviews and personality questionnaires have yet to be integrated into the analysis. Each promises to further clarify and enrich our understanding of participants' engagement in the Sonified MirrorGame. To connect our findings to earlier work (e.g. Noy et al, 2015), it would furthermore be important to calculate and include co-confidence as an additional measure of movement coordination in our analyses.

In future work, it would be interesting to explore jointly improvised behaviour with a **relatively more predictable and less dense interactive movement sonification**, so as to approach the sweet spot between variation and predictability that (as we argued) may be central to creative social interaction and know-how. As pointed out above, future work should also address the open question of assessing and integrating interpersonal experience dynamics, as well as sensitivity to a diverse range of contextual factors, in laboratory-based research on social cognition.

Together, my findings from the BallGame and Sonified MirrorGame demonstrate intricate relations between embodied and mental engagement in social interaction, support an understanding of social behaviour as an interactively maintained and situated process, and provide a collection of useful tools and promising starting points for further interdisciplinary research on social interaction.

**Central emergent themes**

To summarise and discuss my laboratory work, I revisit my findings organised around three themes that emerged as central:

***Context matters.*** Findings from two multi-level analyses of interactive coordination and experience highlighted the role of the interaction context. In the BallGame, both experience and movement coordination were affected by whether players had the same or complementary information about the location of obstacles. Interpersonal movement coordination was furthermore higher when the ball was close to mutually visible objects - regardless of the game condition. We also identified personality difference between players (which could be considered a context for their interaction) to influence game concurrent agreement and predictability ratings. Similar levels of ambition and discipline (trait conscientiousness) increased players' predictability ratings, and shared proclivity for action, optimism, communication and stimulation increased agreement ratings. Interestingly, we also found that predictability was enhanced by differences (!) between players concerning their tendency for altruistic and empathic behaviour (trait agreeableness). This might be explained by complementary roles taken on by members of such teams, as discussed in *Chapter 3A*. In the Sonified MirrorGame, in turn, manipulations of the interaction context strongly affected participants' experience and behaviour: the sensory feedback modality was by far the most influential predictor of social experience and interpersonal movement dynamics. The leadership instruction likewise affected participants' experience and behaviour across the board of analyses we performed. In short, visual feedback enhanced fun and fluency and prompted expressive and playful modes of interacting, whereas auditory feedback led to slower, more careful and intuitive exploration, and at times a stronger sense of embodiment.

Meanwhile, participants tended to prefer joint improvisation, where they moved more synchronously but otherwise showed lower levels of movement coordination. The findings from both experiments exemplify how interaction dynamics form around what is available: where we are influences how we relate to each other, and makes specific modes of interacting and coordinating more readily available than others (see also, Rietveld et al, 2013). A reductionist logic is difficult to apply: even empty (or technical) space conveys a set of affordances. It therefore appears central to reconsider and more actively work with a wider variety of effects of context in future research on social cognition.

***Balances matter.*** Balancing processes were at the heart of how participants solved the interactive coordination tasks they were presented with. Participants oriented themselves and navigated the game environment by balancing synchrony with variability, and performance with exploration. They also sought to accommodate their own as well as their partner's preferences over the course of the interaction. In other words, they enjoyed the game when they accomplished a balance between predictability (familiarity, structure, a well-honed repertoire) and surprise (novelty, variability, exploration, laughter, playful tension and difference). My findings therefore suggest that engaged social interactions thrive on opportunities to interactively set and (and continuously re)calibrate such balances. A balance between predictability and surprise, as well as room for personal and interpersonal autonomy also provide potent experimental design criteria: are the experimental task and stimulus, overall protocol and environment in this sense balanced? My call for future research to explore a relatively more predictable interpersonal movement sonification fits with these considerations. Overall, non-instrumental approaches that consider active participation on behalf of the participants in their design, hold the space for exploration and engagement during the experiment, and consider participants' perspective during the analysis appear central for the study of relational processes (see also, Dumit, 2014; Brinck & Reddy, 2019).

***Integration matters.*** The research question at the heart of this thesis required me to move back and forth between distinct data types and formats, each with specific analysis methods and their associated constraints (on hypotheses, operationalisations and conclusions). This activity generated a rich field of challenge and mutual inspiration, with a seemingly endless tail of follow-up questions. I find this level of complexity appropriate, given the nature of the phenomenon at the heart of my work: experiential and movement dynamics at play during social interactions. A concern for integration not only describes my work as a researcher, but was also present in participants' experience of the interactive games. In both studies, participants emphasised listening, and found moments in which they recognised their partner's distinct perspective but could maintain a reliable interaction dynamic particularly rewarding. They also remarked on moments of reflection or insight about themselves as part of the experiment. Note that both aspects (connection between self and other, insight about self) resemble elements highlighted as central for successful micro-phenomenological interviews (Heimann et al, 2022). In the Sonified MirrorGame, a large group of comments on special interactive moments furthermore involved metaphors and associations - images that integrated participants' experience of the Sonified

MirrorGame with other domains and situations that form part of their lives. In short, my work suggests that participant engagement - and thus research on engaged social interaction dynamics - benefits from opportunities for participants to actively create the structure through which they then interact (see also, Hall & Stevens, 2015, on the importance of developing trusting relations and a working consensus; or Walton et al's, 2018, work on joint musical improvisation, which suggests that the absence of dominant external structure contributes critically to creative interaction). In addition, asking participants how they connect the experience in the lab to their everyday life could inform researchers about the underlying motivations that allowed participants to form shared intentions (see Knoblich & Sebanz', 2008, work on the relation between shared intentions and complex interpersonal coordination). Finally, the use of several methods of observation and their subsequent integration in iterative cycles of analysis that ideally involve feedback and collaborative exchange among several researchers seems needed to grapple with the complex set of relations at play during social interactions.

**The relevance of *context*, *balance* and *integration* in light of my applied work**

The three emergent themes I identified provide a strong bridge to the applied projects I engaged in to implement enactive and embodied views of cognition in my research practice.

The Playful Academic was literally about the use of context to develop our embodied, situated and interpersonal attention and sensitivity: the scores we provided offer clear instructions to guide researchers into different modes of attending and interacting. Across the set of scores we furthermore balanced embodied and situated with reflective and social practices. Ideally, the opportunities for dialogue and reflection included throughout the protocol, as well as our explicit invitation (and concrete suggestions for how) to modify the scores, further allow 'playful academics' to integrate their creative exercise into their ongoing research projects.

From my work with the Mindful Researchers, in turn, I learned about the key role of social context. Our group is marked by shared commitment to grounding practices and interactive manners and habits that emphasise co-creativity: recognising, supporting and responding to each other's motivated proposals. Being a member of such a working group allowed me to clarify my research questions and strengthened my ability to notice and express insight from experience. In discussions about our way of organising, we furthermore touched explicitly on the topic of balance, in particular between process and outcome quality, both of which seem vital to sustained commitment and personal initiative. Collaborative facilitation of personal initiative as a modus operandi requires strong listening and integration skills: in order to move forward as a group, members have to be(come) articulate about their motivation and its pragmatics, and the rest of the group ready to listen and be affected, offer feedback and get actively involved. As such, our work with the Mindful Researchers asks us to stay curious and keep a steady but not rigid (fresh) focus on the intentions and sense of possibility we hold individually and as a group. I have come to see that this (personal and integrative) way of working not only confronts us with others' but importantly our own views (biases) and approaches. It prompts us to reconsider our sense of security (identity, place, recognition), freedom (rest, well-being, movement, possibility), and desire (motivation, attraction, rejection), all of which influence how we (can) engage in social relations and collaborate as a team. In other words, I find that our work trains leadership skills.

**Avenues into co-creative research**

My doctoral work set me out on a clear path: I investigated cognition as an embodied and situated phenomenon and attempted to open the doors of the cognitive science laboratory towards the complex set of mutual relations at play whenever we encounter another. In the process, I designed experiments and analysis frameworks that approach interacting individuals through several channels and techniques of observation. This work taught me about the importance of context, balance and integration: when we enter social interactions, we orient by looking for a set of balances - between predictability and surprise, performance and exploration, our own and others' interests and leadership, as well as between a focus on relating to the other and our non-social environment. In particular, we (enjoy to) continuously reset this balance, individually as well as in interaction. By doing so, we learn about our environment, our and others' needs and interests, to assemble a growing repertoire of (situated, contextualised) tools to relate, experiment and be transformed in the process.

The insights I gained into social interaction dynamics changed my understanding of research settings (experiments, laboratories, collaborative work): instead of tightly run protocols, I now think of them as curated but open spaces - designed to ask a specific question but welcoming towards participants' diverse backgrounds, curiosity and creative exploration. In the future, I therefore want to work with experimental settings that involve participants as co-researchers - at eye level with each other, the experimenter, and the research process. This involves careful preparation based on what I have learned (about the phenomenon at the heart of my research question), but equally requires open space and invitations that call on the environment as well as participants' diverse backgrounds of experience to shape and contribute to the investigation. While presenting its own set of challenges, I believe that such research generates powerful datasets and leads to concrete and well-informed follow-up questions for all parties involved in the process. Such an approach would also draw in the specific life-world (professional and personal relations, rhythms of life and decay) that ultimately sustains the state of affairs I set out to investigate. Indeed, I would argue that research settings (including their methods of observation and documentation) are best curated by a community of researchers that had the opportunity to develop trusting relations. After all, science - the collaborative endeavour of constructing and organising knowledge in the form of testable explanations and predictions of empirical data - flourishes when diverse minds come together in a spirit of curiosity, collegiality and creativity. I therefore close by stating that besides rigorous methods and well-informed experimental design, my doctoral work taught me that it takes courage, a strong will that recognises but does not cling to ideas, and space to play and exchange with *others*, to become a professional researcher.


**Figure C5.3** A colourful note drawn while listening to a recording of myself reading the text of the discussion. Photograph taken close to the shore, Nebel, Amrum.

# EPILOGUE

Next to the laboratory work I conducted to investigate social sensorimotor contingencies (Chapters 3 and 4), my doctoral research inspired me to form research groups to (learn how to) implement my theoretical background directly in the way I work as a researcher. The epilogue introduces the two most extensive projects that emerged from this line of work: the **Playful Academic (Epilogue 1)**, a set of scores to bring improvisation practices and awareness of body and space into collaborative research; and the **Mindful Researchers (Epilogue 2)**, an international initiative and network for regular meeting and exchange, intended to ground professional work in contemplative, embodied and relational practice.

Why bring play and playfulness into academic work? To quote Rikke Toft Nørgård, editor of the Journal of Play in Adulthood, playfulness in academia involves:

> "*the courage to take risks in research, mess around in teaching, revolt against the academic metrics and subvert the system if it proves to be unethical. The creativity to play with words and worlds, to have 'Forschergeist' (spirit of research) in exploring and experimenting and to be open to being taken over by the play of the world. And caring for the heart, head and hands of academic practice so that it dares to play, to care for and play with others sometimes at the expense of yourself (or your ambition) and to care for the world as you play with it and it plays with you."*
>
> *(Toft Nørgård, Solheim, Buckholt, 2021, p.33).*

Our intention with the Playful Academic was to make some of these ingredients fruitfully available to collaborative research.

The Mindful Researchers initiative, in turn, focuses on individual and collective forms of practice, as well as organisational structures and resources that can strengthen embodied and relational awareness. In particular, the co-creation of such structures through collective commitment and investigation.

Both projects aim for a thoroughly relational (embodied, enactive) research program in the cognitive sciences. They seek to build routines and approaches that take into account the inter-relatedness of bodily, personal, inter-personal and environmental factors, and hence welcome relationality - our ability to ground, orient and make sense through embodied interaction with the world and others present in it. By emphasising the importance of grounding and sensitivity to context and situation, as well as integrative and transformative aspects of research, both projects work towards a more liveable academic practice. By encouraging exploration and the association of differences, they further foster creativity. Overall, the approaches proposed in the Playful Academic and Mindful Researchers may thus generate research outcomes that are considerate of multiple perspectives, and hence more objective and meaningful.

# EPILOGUE 1: THE PLAYFUL ACADEMIC

Inspired by the desire to 'practice what we preach' as embodied and enactive cognitive scientists, Katrin Heimann, Pedro Gonzàlez-Fernàndez and myself embarked on a collaborative endeavour that led to the creation of a set of scores - practical instructions that use simple constraints to introduce play on awareness of body, inter-subjective dynamics and environment as a viable and generative aspect of academic research.

My work on the Playful Academic was supported by the 'Varela Award' - independent funding that I received from Mind & Life Europe to enhance the integration of qualitative and quantitative approaches in the cognitive sciences.

**Epilogue 1** presents the article we published in *The Journal of Play in Adulthood*, as part of their special issue on *Playful attitudes, approaches and activities in learning, teaching and research*[6]. The article motivates the relevance of playfulness for academic work, outlines ease and sensitivity to one's diverse experience as conditions for playful learning, and introduces scores as a means to facilitate playful research collaborations - in general, as well as through a particular set of scores that provide an easy starting point for researchers to pick up this work. The article also includes an evaluation of the protocol for the Playful Academic, as well as the collaborative process of creating it.

> Lübbert, A., Heimann, K. & Gonzàlez-Fernàndez, P., (2021) From What Is to What If to Let's Try: a Treasure-Box for the Playful Academic. *The Journal of Play in Adulthood* 3(1), p.52-70. doi: https://doi.org/10.5920/jpa.875
>
> Author contributions: AL, KH and PGF developed the scores and protocol. AL and KH wrote the article (with input and feedback from PGF). KH and AL conducted the pilot assessment of participant experience in playful academic sessions.

**Appendix III** of this thesis provides supplementary materials to the work presented in *Epilogue 1*. This includes the complete protocol for the Playful Academic, a guide for facilitators, and the thematic content analysis of participant reports that we conducted as part of our evaluation.

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[6] Find the special issue and article at https://www.journalofplayinadulthood.org.uk/issue/83/info/, and https://www.journalofplayinadulthood.org.uk/article/id/875/, respectively.

## Epilogue 1

## From What Is to What If to Let's Try: a Treasure-Box for the Playful Academic


### Abstract

Academia is the global institution for higher learning. Its job is to gather wisdom, develop skills and educate new generations of researchers. Over the last decades, ever more scientific research points to playfulness as a key ingredient of sustainable learning environments. Nonetheless, academic culture largely ignores or even suppresses playful engagement. In this paper, we address this paradox: as three researchers from different disciplines, we compose a set of concrete activities to support playfulness in academia. Here, we present the process and preliminary outcome of this collaborative endeavour: we introduce the concept of playfulness (a motivational loop) and philosophy (4EA cognition) that informed our approach, motivate our particular choice of method ('scores' and a selection of movement and awareness practices), and document our playful exploration in the form of a protocol, empirical evaluation and supporting documents that make our results available to other researchers. As such, we promote playfulness as a sustainable learning practice, and invite you to join us in bringing it to life in the lab.


### Introduction: play as a rigorous, liveable and creative academic practice

What if you woke up being a researcher and teacher at university? What if this meant looking back to an academic education that helped you identify the research questions most meaningful to you, in your environment. An education that motivated and prepared you to give yourself to these questions, daily anew. What if each day you woke up to the tickle of: Where will this day lead me? How will I manage today to doubt myself, to challenge what I thought yesterday, to go further, beyond myself, to have fun, to surprise myself, to make a difference AND genuinely involve others in that process?

Academia is the global institution for higher knowing and learning: the public administration responsible for fundamental and applied research, certified scientific and technical education, and thinking of alternative solutions and liveable futures more generally. As such, a high-quality learning environment is a key responsibility for academia, as is for instance outlined in the Lindau Nobel Laureate Guidelines (2020). Nevertheless, a rising number of academics warn about unsustainable working conditions affecting both the health of the academic workforce, as well as the quality of the knowledge it produces (see Trakakis, 2020; Nature Editorial, 2020; Look beyond publications in assessment of PhDs, 2019; A kinder research culture is possible; 2019). These critical voices portray a system that prefers "fast science": a blind hunger for unambiguous results published and recognised in as many high-ranking journals as possible, over what might be called "slow science": the careful design of spaces and coordinated activity that can sustain paradox, support critical refection of difficult questions and generate context sensitive learning and documentation, by transparent leadership that genuinely engages the diversity of perspectives involved, including from the public sector (see Frith, 2020; Caron, 2020). Expected to immediately deliver unquestionable results, scientists often forget to think about the questions that really mater to them, alone or together, and refrain from voicing doubts or staying with the troubling complexity that inevitably tends to emerge along the way of a research project. Avoiding to muse uncertainty and not-knowing, we are less likely to notice the limits of our understanding, and thus to go beyond what we already know (Myers & Dumit, 2011). Statements that involve personal experience in general tend to be judged worth less than statements presented as the outcome of an established methodological procedure. However, personal experience remains our most immediate access to the world - our colleagues, abstract ideas, our surrounding or other material. A disqualification of lived experience therefore not only affects our health by promoting stress and depression, it also cuts us of from insight, motivation and creativity. As a consequence, we respond less to - take less responsibility for - the world and others.

In 2019, the British environmental activist Rob Hopkins published From What Is to What If - Unleashing the Power of Imagination to Create the Future We Want. The book asks us to stop doomsaying our present and future given the severe sustainability crisis we live in. Sole criticism can easily culminate in resignation and depression rather than activism. Instead, the author suggests, we should get together and draw from our imagination, think of liveable alternatives and realise, test and develop them in our immediate environments. One of the major ingredients Hopkins brings to his imagination workshops is playfulness. Likewise, over the last decades, ever more scientific research in kindergarten and schools, but also companies and organizations has pointed to playfulness as a key ingredient for life-long learning and sustainable transformation of individuals, groups and society as a whole (Resnick & Robinson, 2018; Hirsh-Pasek, Golinkof, Berk & Singer, 2008; Farber, 2019; Lin, Lin, Chen & Teng, 2010). However, despite these results and the central role of learning, change and collaboration in all aspects of the academy, playfulness is still a rarely discussed and even less often promoted topic in academia - possibly due to the above described self-image of academia (that is to provide objective, rigorous and flawless work), which conflicts with what we intuitively understand as "play".

This article presents our attempt at following Hopkins' spirit of pragmatic and imaginative solutions to support sustainability and break with the lack of play in academia. In three steps, we browsed our research methods, repurposed our academic tools to build an extendable toolbox for playful academic collaboration, and test our result with ten co-researchers: Based on a study published by the third author (Heimann & Roepstorff, 2018), we first present our description of what it means to become playful. In reference to 4EA cognition, we furthermore outline what we believe to be essential preconditions for entering a playful state of mind. Inspired by art-science collaboration, in particular their dual nature of being both an intervention and a research project (Chilton & Leavy, 2014, Frayling, 1993; Sleigh & Craske, 2017), we then entered an iterative design process to create tools that allow us to slowly gain the knowledge and technique for the desired change. Here, we present our outcome: a protocol of activities designed to support the conditions for playful academic work - a structured set of activities for each of you to try them out in your own research groups and environments. Thirdly, to better assist and welcome others into this process, we provide data on participants' experience with the protocol, as well as refections from our own experiences with its design and facilitation. Let us begin.

**What do we mean when we say playfulness?**

Play is a term often associated with children, toys and games specifcally designed or repurposed to allow entry into exploratory processes for the fun of it (Garvey, 1990). Playfulness, in turn, is mostly studied as a personal disposition: a combination of personality traits that allow a person - child or adult - to lead their lives with more ease and fun. Playful people, so the assumption, are naturally more inclined to use their intellect and creativity to recontextualize any situation as "play-like" (Proyer, 2019).

Recent research suggests yet another perspective on play: while context and personal dispositions do mater, the capacity to be playful is universal - it is in principle accessible to anyone, anywhere (Bateson & Martin, 2013). For example, Heimann and Roepstorf (2018) asked participants to perform a brick-building task in two conditions: once so that it feels as playful as possible and once so that it does not feel playful at all. Afterwards, participants were interviewed about their subjective experience of performing the task under the two different instructions.

The reports reveal a series of micro-gestures to transition into playful states of mind that is very similar across participants. Because it is central to the work we propose here, we introduce this in detail:

The first of the gestures that participants perform to enter playfulness is to free themselves from any given or anticipated set of rules: they start the process with a feeling of autonomy and agency - "If I want to be playful, I need to do whatever I want". This self advice seems to help participants expand their repertoire of actions beyond the explicit instructions provided (such as on precisely what to build). It also affords them a different kind of engagement with themselves, their environment and especially the building material they were using for the task: participants who reportedly reach a playful state describe a sensual, in some cases even aesthetic relationship to the bricks, an enjoyable and surprising experience of "becoming aware" of tactile and other perceptual qualities. Their reports furthermore indicate that such heightened sensitivity leads to a process of "fiddling" with the material - an open-ended process in which participants let themselves be guided by the sensations, affects, ideas or movements that emerge in their intimate interactions with the bricks. It was, in the words of one participant, "as if the bricks took over" - as if participants' cognition got extended by them. From there, boosts of creative building acts emerge: outcomes that generate strong surprise and fascination ("I could not have planned what my hands and the bricks came up with"). The associated positive emotions ("Wow. I did not think I was able to build something like this"), in turn, seem to heighten participants' feelings of competence and autonomy, and leave them eager to continue the exploration and start a new building project. As such, the micro-gestures that Heimann and Roepstorf (2018) identify as inherent to a playful state of mind form a loop: playfulness tends to feed and facilitate its starting conditions.

**Creating the Conditions for Playful Learning**

Notably, the study also reveals the difficulties involved in becoming playful. Specifically, a number of participants report that they do not manage the crucial step of freeing themselves from the situational demands they experience. They feel observed, and their minds are busy predicting the researchers' expectations to fulfil the experimental task in all its dimensions. Instead of opening a space for intimate exploration, the task puts them under pressure to perform 'according to plan'. As a consequence, they describe their experience as boring and uncreative, leading to insignificant outcomes that leave them with a feeling of frustration rather than the motivation to try again[7].

Experts in the field of learning therefore point to the fundamental importance of setting the right frame: to create an environment that makes do without hierarchies and performance pressure by focusing on the well-being, interest, abilities and co-creativeness of the learner (Andersen & Roepstorf, 2021). When this discussion reaches university classrooms, it promotes teachers as facilitators rather than instructors, and equips them with tools to - for instance - provide (peer) feedback and other means to check the acquired knowledge in non-intimidating ways (Tompkins, 2018; Almagor et al, 2018). A similar trend can be observed in experimental design: as researchers become increasingly aware of the detrimental effect of demand characteristics (such as described above) on the ecological validity of their results, they are looking for ways to create testing environments and use tasks that speak to participants' interest and intrinsic motivation (Latour, 2013).

Viewed in light of Heimann and Roepstorf's (2018) playful loop, these approaches work towards creating safe spaces, making room for autonomy and agency, and supporting fun and well-being. However, they only look at students or research participants - forgetting teachers, researchers, professors and anybody else involved in academia. Furthermore, what is lacking is the element of sensitivity or surprisingly intimacy: the simple but powerful act of paying attention to the diversity of one's ongoing experience. In our view, such sensitivity is essential: it allows us to effectively "fiddle" - to develop a deeply intimate, in the sense of border blurring, interaction - with the entire spectrum of our own and others' experience, and thus to learn, transform and change in mutual response to our environment (Sleigh & Craske, 2017; Myers & Dumit, 2011). On this basis, we are ready to overcome our own habits and biases, and engage in the kind of intelligent and resilient collaboration that unforeseeably but almost definitely leads to breakthrough discovery.

Before we introduce our particular approach to facilitating sensing, deep listening and tentative manipulation in everyday academic life, we take a moment to elaborate the theoretical background that informs our work: so-called 4EA cognition.

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[7] 'Der Mensch spielt nur, wo er in voller Bedeutung des Wortes Mensch ist, und er ist nur da ganz Mensch, wo er spielt', Schiller, 1993 (translation: 'a person only plays where she can be human, in the full meaning of the term, and is only entirely human, where she can play'). See also a report by The Royal Society, 2019, on academic research culture.

*Cognition is Embodied, Embedded, Extended, Enactive and Affective – say what?*

According to embodied, embedded, extended, enactive and affective cognition - in short, 4EA[8] - how we perceive the world, think of it and act in it is one fundamentally entangled process. Metaphors of automats or computers that passively register and discriminate between different inputs, process and react to them according to preprogrammed algorithms fall far short of reality. Instead, as the 4EA framework suggests, we enter a situation as motivated and alive individuals who hold particular questions, which fundamentally shape the type of answers and stories we (can) come across, and integrate them into our thoughts and actions. Put simply: the net that we use determines which fishes we can catch. At the foundation of cognition, proponents of 4EA research imagine a large network of mutual influence that connects a diversity of elements. Importantly, they portray our central nervous system as but one member of a family of biological, personal, socio-cultural and ecological substrates of thinking. More concretely, and applied to the working life of an academic, we distinguish the following five levels:

At the first level, we focus on the important role of our cognitive-affective states for our work-life. The personal motivation we bring to our work, the value we see (or do not see) in our research questions, methods, broader approaches and outcomes, is decisive for whether or not we are able to sustain our research interest over decades of our life. Furthermore, our affective states and resonances suggest action possibilities beyond culturally impregnated norms and procedures - recognising them can be extremely helpful in picking up on subtleties of dialogues and argumentations in reading, writing, listening or talking. It is crucial for navigating work related social situations in a non-violent manner.

On the second level, our body plays a crucial part in how we perceive and act in the world: Our body size determines our natural perspective, our posture how long we can sit without pain, our sex and weight determines the optimal room temperature for working. How we breathe and what we eat is not only fundamentally important to how we feel and thus in what colour we perceive the world, but also to how long of a lecture we can give without losing our voice and at what time we need a break.

On the third level, it is our physical environment that shapes our thoughts and actions: we can have little or plenty of space available, which will afford us to work at particular scales. We might be situated in light or in darkness, sharpening different senses. We may be surrounded by wild infuriating nature or calming concrete, sit on soft moss or lean against sturdy metal, smell Proust's madeleine or an unknown chemical, work with paper and pen or at the computer - all with different effects on our body, affect, lived experience and thus again our work.

As a fourth level, we consider the social interaction dynamics through which we take part in the world and in a work space. It forms the playground on which we develop and test our roles and identity, and it presents us with others' expectations, which we may or may not feel ready to

[8] For an introduction to '4E cognition', see Newen et al, 2018. Further key references and wonderful entry-points into this field are: Varela, Thompson & Rosch, 1991; Varela & Depraz, 2013; O'Regan & Noë, 2001; De Jaegher & Di Paolo, 2007; Thompson & Stapleton, 2009; Kirchhof & Froese, 2017; Nummenmaa, Glerean, Hari & Hietanen, 2014; Fairhurst & Dumas, 2019.

meet. Our relation to others might well be the greatest source of both motivation and despair, inspiration or boredom, activity or passivity, depending on the circumstances.

Lastly, we consider the influence of concepts, tools and culture on our work. This comprises the language(s) in which we communicate, the ideas and platforms through which we manifest and reflect our experience, and the particular methods and materials we use in our work. We also consider the rules and habits modelled by influential individuals, the research groups we form part of and our academic discipline as a whole to form part of this level. The processes and products that we agree to cultivate, as well as the traditional ways of our profession shape the way we investigate the world, what of it we discover and how this affects us.

According to 4EA, our cognitive abilities depend on all levels, equally. We therefore think that we must take each of them into account when we attempt to support a more playful academia. As a consequence, we propose an academic "routine against routines": an activity that makes us sensitive to our existence across the levels we describe above, that opens opportunities to enter playful exploration at each of them, and that supports us in integrating the diverse experiences we make. This, we argue, should not only lead to a more enjoyable, challenging and enriching work process, but also generate innovative outcomes. Our approach resonates strongly with research programs such as somaesthetics, enactivism / neurophenomenology, critical co-constructed auto ethnography, as well as the emerging field of art-science collaboration, all of which acknowledge and strive to integrate more 'objective' as well as more 'subjective' perspectives[9].

*Scores for the Playful Academic*

As we planned this article, we first considered to outline these thoughts in writing, including refections on our own work habits. We quickly realized, however, that this left us - and would likely leave the reader - with the unsatisfying feeling of a big but empty promise. We then asked: how could one concretely go about facilitating 4EA awareness and playful interaction within academic contexts? And would such facilitation really lead to the anticipated effect of more sustainable and creative collaboration and learning?

Finally we thus took Rob Hopkins advice: instead of analysing the status quo or theorizing in search for the perfect alternative praxis, we would draw from our expertise and imaginative capacity to design and test a small scale, manageable intervention to bring about the change we envisioned in our immediate environment.

More concretely, based on Pedro's background in performance arts and his experience as an improvisation teacher, Kat's track record in art-science collaboration and Annika's work at the

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[9] Shustermann, 2012, provides an overview of somaesthetic perspectives. Varela 1996, as well as Varela & Depraz, 2003, describe the enactive / neurophenomenological approach. Cann & DeMeulenaere, 2012, present a critical co-constructed auto-ethnographic approach. Recent examples of art-science collaboration include EER and ARTIS. See also Wenger, 2000, for an account of learning based on communities of practice.

intersection of somatic education and cognitive science, we decided to create a series of scores to lead us into academic work of a different kind.

A score is essentially a set of clear and simplified instructions to guide participants into exploration - be it in a real or virtual environment. In music and dance, a score is meant to convey a deep intuition, intimate knowledge, by transforming it into a structured task to be performed in a specific time frame according to easy to follow instructions. Successful scores thus lead to a complex output with the minimum possible pre-knowledge and effort expected from the receiver.

**Contact Improvisation** (CI), is a modern dance form that - therein similar to Feldenkrais - seeks to expand our bodily repertoire. CI practitioners are interested in exploring all movement possibilities of the body - a single body in relation to the floor / environment, or several bodies that share weight, roll, slide, swing or climb across one another. Originated in New York in 1972 in an avant-garde movement exploration by the American dancers and choreographers Steve Paxton, Nancy Stark Smith, Daniel Lepkoff and Nita Little, CI is today taught around the globe. A central principle of this practice is to stay aware of moving without pursuing any particular goal or intent. To exemplify: in a *small dance* - a solo practice of standing upright - CI dancers observe the micro reflexes of their body that allow them to maintain balance. Or, in a *rolling point*, two dancers focus on a single point of physical contact between them, which they keep moving at roughly the same speed and intensity. While none of the scores presented directly invites for a touch improvisation, the drawing activities 1 and 4 rely on similar principles of moving and producing in interdependence and attunement to others.

Another important part of CI knowledge is the care taken to open, facilitate and close a session. A good practice offers everybody time to arrive physically and energetically, before entering into contact with others. In CI, you practice arriving somewhere *through* a moment of bodily relaxation and 'strolling' - you walk around, lie down, take a couple of deep breaths, taste and follow the path of interesting movements. Throughout the time of practice, teachers furthermore encourage a stance towards the room as a playground and towards others as welcome participants in one's personal exploration. When anybody takes a pause or retreats to the edge of the practice space, CI culture is to still consider them an active part of the practice, a witness whose attention matters just as much as that of those more centrally involved. While hard to pin down as inspiration to single activities, we recognise these principles as key to our entire endeavour and tried to design the entire protocol allowing for their realisation.

A **Listening Circle** is an intentional space to share experience. The practice is referred to as council or sharing circle, and is based on the ancient tradition of gathering around a fire to tell stories. It usually begins with a reminder of its form - there is a beginning, an end, a center and a talking piece - and its principles: (1) to listen with one's whole self (at a conceptual/mental, emotional and physical/bodily level, as well as to the general atmosphere in the group), (2) to share stories from one's own life, (3) to wait until the essence of an experience has settled (to express the essence), (4) to share spontaneously, without too much planning or judgement, (5) to share something of service - to oneself, those present, and all other beings, and finally (6) confidentiality - the agreement that we may harvest richly from our own experience, but that the stories shared by others should stay in the circle. After a reminder of these principles, the practice proceeds with a moment of grounding (someone guides a contemplative or embodied awareness practice for everyone to arrive more fully). It then opens up for anybody to voice intentions and dedications for this time in circle, and enters into sharing and witnessing of the stories that are present in the group. Listening circles, or more simply the opportunity to hear voices and reflections, to digest and compost experience as a group, can be instants in which a whole group participates to set and shift their context and purpose. In the protocol, we integrate a (reduced form of a) listening circle in activities 5 and 7. Similar to the input in the box on contact improvisation, the ideas we outline in this box furthermore speak through the instructions in the protocol, as well as the content and approach presented in this chapter.

Importantly, such output is flexible: scores should animate rather than guide, giving impulses for development in many possible directions: through the right level of definition, scores explicitly define one level of interaction and establish a game dynamic that everybody can easily enter. At the same time, they provide hidden affordances along other dimensions not initially apparent to the participants. Therein, they leave ample space for exploration, uncertainty, discovery and surprise. By including the entire spectrum of activities from performing to exploring and experimenting, scores are wonderful candidates for transporting and at the same time generating knowledge as a diversity of evolving path (Løppenthin et al, 2022). They provide a horizon of opportunities, and space to rethink and decide for oneself, after having gained some experience. We highlight this quality by calling them play-frames, not game-frames (Hanus & Fox, 2015).

**Feldenkrais** is a somatic education developed by Moshé Feldenkrais to expand our bodily repertoire. It often involves instructions to perform minimal movements in extreme slowness and to attend to such in great depth and detail, but can span a range of movement dynamics. Simply by attending, we involve more of our body/self and discover new ways of moving. As a consequence, difficult movements gain in composure, efficiency and resilience. Frequently, this alone can resolve tension and resistance in the body, to the effect of softening or even overcoming old or life-long bodily habits. In our protocol, Feldenkrais is the main inspiration for the writing/scribbling score provided in activity two, which is designed to sharpen our awareness for our own body and affective state while we work, and could be the basis of a range of similar tasks.

**Micro-Phenomenology** (MP) as developed by Claire Petitmengin is a method of guided introspection: experienced interviewers help interviewees become aware of their subjective experience and enable them to describe it in fine-grained detail. MP reveals the bodily and mental life of a person in any moment of their existence - including emotions, images and mental speech but also more complex experiences such as trans-modal feelings or thoughts. By offering time and skilled attention to which is happening to us, MP presents an opportunity to go beyond socially constructed concepts and interpretations of what we live through. In the protocol, in particular activity 5 is inspired by MP: it invites you to notice what exactly you experience when you read or listen to a test, an activity central to the academic profession. And while neither of our tasks comprise a structured interview setting, our experience with the method again influenced the way we formulate the scores - trying to stress the value of attending to the lived moment rather than meta-thoughts, to listen rather than to think, to wait and search for the right description rather than to simply use common metaphors that make it easy to oversee the gap etc.

**Improvisational Theatre** extends play to the realm of words, roles, language and culture more generally. It animates us to be "the other" - in the sense of taking on the role of a character different from our usual selves. Rather than through abstraction, this is done in deeply embodied study: in iterations of embodying emotional states and reflecting on their lived effect, performers bring themselves closer to the experience of their character. As expressed by Konstantin Stanislavski: "When I give a genuine answer to the *if*, then I do something, I am living my own personal life. At moments like that there is no character. Only me. All that remains of the character and the play are the situation, the *life circumstances*, all the rest is mine, my own concerns[. A] role in all its creative moments depends on a living person - i.e., the actor - and not the dead abstraction of a person - i.e., the role." (Benedetti, 2011). While, again, our protocol does not contain acting exercises as such (though it could), the creative writing scores of activity 6 are related to this praxis. Likewise, whenever we ask you to perform an activity with an unusual focus - such as in activity 2 - we prompt you to delve deeper into a certain way of experiencing yourself, very much akin to the idea of entering a character through your bodily experience.

Scores can provide a shared agreement on how to communicate and provide feedback in the group, and allow us to organically combine rather different approaches. We therefore propose scores as frameworks for genuine collaboration - to involve participants, their personal histories, and the disciplines in which they are trained in a constructive dialogue.

*Resources – bringing our Context and Background to Play*

In the design-process of the Protocol for the Playful Academic we relied on our personal and professional backgrounds with different movement and awareness practices (Clark et al, 2015). For further information, please refer to the five inspirational method boxes above[10].

**Introducing the Protocol**

In Appendix III, Supplementary Materials A, you find the Protocol of the Playful Academic as it currently stands. What we offer you there is the synthesis of an evolving process: the candidate activities that we selected, explored and identified as potent resources for academic play.

The protocol begins with a poem - an image to mark the beginning of playful exploration and adventure. The first activity we then introduce is called 'Drawing in Circles'. This activity has a social focus. It asks us to pay close attention to our group dynamic, and offers an easy but fun start into working together. The second activity we propose involves the body - 'Drawing from Toe to Ceiling' is inspired by a Feldenkrais exploration and motivates you to stay aware of your body as you engage in a work-related activity, such as writing. In the third activity, we offer you a set of questions for refection: 'Each of Us and All Together' is designed to make you aware of the personal perspective that you bring to this work. Here, we also introduce the form of a listening circle as an intentional space to share refections in the group. Activity four, 'Triangulating space', is another social improvisation game, this time focused on complementing rather than mirroring our activities. It is a score that allows you to configure and organise a space, together. Next, in 'Reading between the Concepts', you get the opportunity to learn about the landscapes of experience that emerge for yourself and the others, as you listen to a text (or other material that you work with). This activity is inspired by micro-phenomenology. It asks you to pay detailed attention, take notes, and later gather and structure these notes as a group. In activity six, you might pick up the material you generated in the previous activity: it is a 'Creative Nonfiction' writing task that offers a number of suggestions on how to play on expression. Finally, the last activity is another listening circle. In 'Diamonds in the Raw', we suggest to finish the collaborative play session by witnessing and harvesting what you have experienced.

We encourage you to take a look at the actual protocol, as well as the Guide for Facilitators provided in Appendix III, Supplementary Materials A and B.

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[10] Beyond the information in the boxes, find more on Feldenkrais in Manning, 2020, on contact improvisation in Lepkoff, 2008, or Koteen & Smith, 2021, on Improvisational Theatre in Benedetti, 2011, on Listening Circles in Linnea & Baldwin, 2010, and on Micro-Phenomenology in Petitmengin, 2006, or Heimann et al, 2022.


**Figure E1.1** Traces from Activity 1 of the Protocol for the Playful Academic (see Appendix III, Supplementary Materials A). AL exploring with two colleagues in Hamburg (Angela-Mara Florant and Lissa Streeter, see thesis *Acknowledgements*).

## Evaluation

### a) Feedback from Participants

As mentioned in the introduction, we think of this project as an ongoing intervention - a research project that loops over design, use and evaluation stages to continue to arrive at best possible, up to date solutions. We therefore tried the tasks while we designed them. The final version of the protocol further inspired four sessions during which we invited fellow researchers to explore the protocol with us - once in September 2020 and three times in February 2021. Subsequent to the experience, we asked for written feedback and performed a formal evaluation of the responses. You can find a complete description of our qualitative analysis approach, as well as a table summarising the results, in Appendix III, Supplementary Material C. In the following, we offer a summary of what we learned from participants' reports.

Firstly, we used participants' comments and constructive feedback to improve the protocol and add to the theoretical background and resources that we provide. In particular, we were inspired to create a 'Guide for Facilitators' (Supplementary Material B). Our main analysis then focused on statements about lived or anticipated effects of the protocol. Participants describe their overall experience as "good", "fun", "interesting", "helpful", "relevant", "enjoyable" or "surprising". More concretely, all eight participants describe immediate positive effects of the protocol on general mood and feelings, such as feeling less lonely/more connected to the others (four participants), feeling a stronger purpose of their work (three participants) and feeling more competent or confident (two participants) or motivated towards it (one participant). They also report joy about the discoveries made during the exercises and curiosity about further explorations (four participants) and voiced experiencing gratefulness for this experience and/or the work with their group in general (four participants).

One participant furthermore remarked that the experience had a de-stressing effect on him. See for example: “It created a different kind of atmosphere and reminded me why I’m here and what I cherish about the group and the work we do, I felt it made a better day for me, I feel happy and less stressed and more of a sense of purpose just now as I write.” (Participant 5)

Quotes also indicated effects of the protocol on participants’ awareness or feeling of presence regarding their own body, their direct environment, the other participants and the work project they all related to. More precisely, four participants specifically commented on the shift of attention afforded by the different tasks and described the surprising effects of this new focus: “The moment I first recall when thinking back is when exploring the space around me and "talking" with a chosen object. It sparked my imagination and made me feel very present in the moment in which personal, aesthetic and spatial thoughts popped up.” (Participant 1)

Five Participants furthermore report that they found the intervention freeing with regard to usual habits of an academic interaction. Specifically they appreciated to “think imagine and create without the need to produce a product with clear function” (Participant 1), to interact with others in a “non-cerebral way” (participant 2) and due to their experience anticipated that “It [the protocol] might enable me to work with less rigid academic rituals and routines and it might give me the opportunity to more freely share and think together with my collaborators” (Participant 1). Such freedom was also mirrored in the actual experience of an extension of bodily and cognitive capacities elicited by the tasks, reported by four participants. See for example: “The writing/body movement exercise was interesting because at first I didn't get it at all and then it was a nice surprise how it changed how I write and how I experience writing” (Participant 2).

Further immediate as well as anticipated effects touched upon participants’ creativity and imagination (enhancement reported by three participants) and their expressive capacities (enhancement reported by one participant): “I think it [engaging further with the protocol] will boost my creativity and help me express things, especially with a sense of playfulness! I suspect this will make my writings and expressions more "lively" and creative” (Participant 4).

Lastly, five participants testified how the exercises elicited refections (about self, environment, work and workgroup), and three stressed its positive effect on their current and future collaboration: “I engaged in the protocol just today and as for now I feel even more connected than before with my collaborators. Part of this is related to the fact that I appreciated to realise that I'm so at ease with them that I can do, without problems, unusual or possibly intimate things like the exercises we did, so I kind of felt that my group is special. I'm pretty sure in the future this will make me even more motivated to keep working with them and most of all do my best in this work” (Participant 8).

Remarkably, while most descriptions referred to effects on professional behaviour, four of eight participants remarked on influence far beyond the work context. “I feel that these kinds of exercise affect my understanding of life in general” (Participant 3).

And finally, despite not having been explicitly asked about this, three participants spontaneously uttered that they wish to engage again with the protocol in future. “Would very much like to do more of the protocols. I can remember coming away from the last one thinking, More of this! More of this!” (Participant 7).

**b) Reflecting the Process from our Perspectives**

In a valuable comment, one of our reviewers asked us to add further refections on our experience with this project: what did we experience - how did our work with playful interventions affect our working process? Did we notice any far reaching or long lasting effects on our academic practice?

To all of us, it was freeing and motivating to work together on a project that we found highly meaningful, if not necessary, to our work as academic researchers. We developed a strong shared mindset of turning idealistic aspirations into concrete actions: to develop tools and habits that allow us to forge our very personal paths into a more playful academia. This sense of common purpose might have been the driving force behind a meeting that we decided to organise as part of this project. For a period of several days, we gathered at the home of KH. Here, we offered each other lived experiences of our methods, prompted us to formalise our intuitions, and engaged in a tedious process of iterative discussion and self-experiment. We each remember real progress from this intense time, during which we put together the final version of the protocol. The playful atmosphere was mirrored in the constant changes the project went through - in genuine appreciation for the input each of us offered, we did not cling to our thoughts. Akin to an improvisation practice, it compelled a certain presence, was marked by aha-moments, softness and a will to change - we were often surprised by where it took us.

However, there were also conflicts and situations that did not feel playful. Looking back at these moments, we relate them to time and performance pressure: when we approached the end of our shared time, or the hand in date of this article, it was hard to slow down, listen and stay open to exploration and ‘the other’ - instead, a potent mixture of time constraints, personal needs and expectations created friction, pushing us into ‘long-time familiar’ power dynamics and hierarchies.

Five months after creating the protocol, all of us have the impression that this work had a tremendous positive effect on us as individuals and researchers. Not only did we use our scores in existing research projects and experienced immediate positive effects such as those reported by our participants. Moreover and maybe more importantly, we felt inspired: our collaborative effort provided us with the trust and courage to take more creative approaches to academic research, and aim to for solutions we truly believe in, even if trying to do so at times confronts us with the habits that pervade our usual work environments.

Nonetheless, we feel this work has just started, and expect it to remain a (likely lifelong) invitation to further exploration and discussion. To close the frame of this article, we now offer a summary and point to important open questions.

**Known and Unknown Territories: Summary and Discussion**

In this article, we introduced playfulness as an important vehicle for sustainable learning and collaboration and faced up the challenge of introducing playfulness in our everyday work in academia, the central place of knowledge-making and education within our society. First, we set the theoretical background by presenting a concept of playfulness that lends itself to the task at hand: a motivational loop that involves safety, autonomy, intimate interaction, and unexpected competence - creating the intrinsic motivation to continue exploring. In particular, we highlighted sensitivity to the whole range of experience as an often overlooked but core component of playfulness. We then identified a suitable form (scores) and useful resources from our personal and professional experience (movement and awareness practices), and entered an iterative design process that culminated in 'The Protocol for the Playful Academic' - a set of concrete suggestions to inspire more sensitive and playful academic work.

Our and others' experience testifies to the potential of our approach: our explorative sessions with the Protocol for the Playful Academic generated unconventional interactions across personal and interpersonal dimensions that were marked by an intimate and candid quality of encounter. They further brought about significant moments of discovery and surprise, as well as the motivation to continue and revisit activities from the protocol in the future. Besides immediate positive effects on mood and atmosphere in the group, our experience suggests that continuous practice can create a lasting shift in work-related feelings and habits: we experience greater satisfaction with our profession and work, enhanced flexibility and stronger intrinsic motivation - the courage to continue to challenge and surprise ourselves.

We also experienced challenges when developing this project. In our analysis, most of such difficulty was related to a lack of time, patience or ability to integrate the unexpectedly arising needs and opportunities with the hard constraints we were facing. While the Guide for Facilitators picks up on several of these issues, we believe that further research is needed to clarify and respond to these challenges.

We have formally tested the Protocol of the Playful Academic with researchers from sociology, anthropology, media science, art, philosophy, cognitive science, physics, music and dance - thus, members of a highly interdisciplinary audience, who did or did not form part of an existing working group. Nonetheless, our experience and evaluation is of course limited and needs to be taken with care: the relatively small number of participants in the formal evaluation process were all colleagues and friends of ours - they might have therefore been more open to the suggestions and approaches we provide. On top of this, our scores were developed and tested in times of the Covid 19 pandemic, which might create special conditions such as a heightened sensitivity to yourself, your colleagues and work, and a strong need for sensing and connecting. The effect of such interventions may furthermore be hard to measure (immediately), and require more and longer term tests and experiments. An important part of this continuous exploration is therefore to widen its application.

Finally, we want to highlight the very different phases that our collaborative experience went through: from open-ended immersive exploration and spontaneous bursts of creativity (mostly when everybody could relax into the group and moment), to strong conflicts marked by a hardened and defensive attitude (as in the intense periods of work before a deadline). While it seems obvious that stressors such as a (real or perceived) lack of time hinder playfulness and cooperation, we think it is important to take a closer look and ask what a comprehensive approach to avoiding such tensions in the first place would look like.

Ultimately, this brings us back to our original points: constraints, differences and the unexpected cannot be avoided, so we better be well-prepared and 'ready' to work together as a group. In our view, this requires (1) clear purpose and intrinsic motivation to engage, (2) trust, empathy and familiarity with the particular characters, abilities and interests each person brings to the collaborative project, and (3) useful tools and procedures that support the process of the particular group, setting and day. We consider this the crux or bottleneck for sustainable collaboration, which we describe as the ability to deliver concrete products and engage deeply in what we like to do, within the particular constraints that we are facing (be that limited time, or the specific demands of a discipline, employer or client).

The activities in the protocol are designed to do exactly this. Importantly, a core feature of this approach is that it invites voices from many different backgrounds to explore the diversity of their experience, together. In this sense, we hope that our article can inspire and support you in joining us on the journey ahead - we would be happy to learn about applications and extensions of our Treasure-Box for the Playful Academic in the wild wild west, east, north and south of pandemic and non-pandemic futures.

# EPILOGUE 2: THE MINDFUL RESEARCHERS

Since August 2020 - in the aftermath of the *European Summer Research Institute* (ESRI), a conference organised by Mind & Life Europe - Wolfgang Lukas, Mary Rees, Willeke Rietdijk, Enrico Fucci, Francesco Noera, Nikola Winter, Dara James and myself have been co-developing the Mindful Researchers initiative: an international network for regular meeting and exchange to strengthen embodied and relational practices in professional research contexts. At the heart of this initiative lies the intention to *co-create* the tools, skills and habits needed to support embodied and enactive (relational) research - from experimental design, method and analysis, to the training and organisation of individual researchers, research teams and institutes.

**Epilogue 2** presents work in preparation. It summarises the development of the initiative and gives an overview of the meetings formats we have used in our work.

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All authors co-developed and participated in the project. AL wrote this chapter in exchange with all other authors.

## Epilogue 2

### The Mindful Researchers

### Introduction: exploring avenues for co-creative development

At its core, the Mindful Researchers are inspired by enactive and embodied views of cognition: an understanding of human knowledge and behaviour in which bodily, social and ecological processes evolve together in constant relation - including the systems that we study and the methods we use for doing so. In our initiative, this view translates into individual and collective forms of practice to notice and ground in ongoing experience, check in from our diverse work and life backgrounds, and co-crate - explore how we can involve our social and physical environments in our thinking and productive activity. As part of our work, we have also realised shared contributions such as conference presentations or the facilitation of workshops and events.

The goal of this work and initiative is to find methods and forms of organisation that support us in grounding and informing our professional practice and environments through embodied awareness and co-creative exchange at eye's level. Overall, the Mindful Researchers initiative functions as a container for reflection and development that is centred on the theme of enaction - understood both as a framework to study behaviour and cognition, as well as an organisational principle.

From the early stages of our work, the Mindful Researchers have held regular meetings and events: in a core team of 'Gardeners', we met (online) on a weekly basis, to develop a shared practice, prepare Mindful Researchers events, clarify and pursue individual and collective research interests, and take care of organisational matters. Once or twice per month we invited a larger community of around 160 international participants to join Mindful Researchers events (likewise online). Recently, we held our first physical gathering: during March 2022, the core team of active Gardeners (all co-developers except Dara and Nikola) spent a week together on Amrum, an island in Northern Germany, attending from across Europe as well as Mary from Texas, USA. Besides getting to know each other better, we used this time to deepen our shared practice, continue our conversation around organisational matters and opportunities to do research together, formulated guiding principles, and started to write reflections on our work as Mindful Researchers.

Our activities are marked by an emphasis on practice and a commitment to ongoing renewal and development. We use generic embodied contemplative practices, co-facilitation and participatory (co-design) protocols to structure our meetings and identify common grounds, key themes and core questions. This allows us to build flexible structures and the skill-sets required to listen and learn from each other's curiosity. As a consequence, our inquiry evolves through our (Gardeners) as well as others' motivated participation (thinking mainly of the larger community of people we connect to through our individual networks, the Mindful Researchers newsletter and our (bi-)monthly events).

Our meetings usually begin with a short grounding practice - we ring a bell, sit in silence, or someone guides a contemplative or embodied awareness practice for everyone to settle and arrive more fully to the group. From grounding, we move into a check-in: an opportunity to enter the group space by sharing about one's current state, day or ongoing background of personal and/or professional activity. From here, we move into further rounds of sharing, often guided by an agenda or a thematic prompt, sometimes prepared and offered by rotating teams of facilitators. This is particularly the case for (larger group) Mindful Researchers events, which are often structured according to a specific format, such as a Listening Circle, Mindful Presentation, Co-creation or Playful Academic session (see below).

Regardless of the meeting format, our intention is to support each other in noticing and sharing important dynamics from our experience. This can be supported by (or requires) a sense of ease and trust among those present - the impression that differences are met with grounding (embodied awareness, noticing) and an eye for curious exploration (how is this meaningful or interesting for whoever is sharing and/or me?). Our facilitation style is an important means for accomplishing this: based on the regular practice and relationships that have formed in our core group of Gardeners, we (can) provide a lived example of welcoming experience and work with the opportunities (and challenges) of the moment. This may make it easier for others to notice and express their perspective. As such, we encourage spontaneity and speaking to what matters or is present now, without the need to justify or respond to what was said before. The conversation can then harbour very distinct views. Variety and tension in the group may become more visible and bearable, as the group offers support through listening. Besides the immediate benefits for well-being (that are noticed and expressed by many participants), sustaining this quality of group interaction leads us to think at the edge of what we know and can imagine, individually and as a group. Our dialogues and practice further employs structured formats. Thus: starting in existing forms of practice (Listening Circle, participatory design, open conversation, generic forms of contemplative and relational practice), we co-create the structures and environments needed to support our inquiry. In a continuous learning experience, we seek to flexibly accommodate newcomers or unexpected courses of events: perhaps the most essential principle of our joint project is to remain open and welcome emerging ideas and participants at whatever level they wish to engage. Thus, instead of reinforcing existing (social, organisational) norms, we (learn to) facilitate group dialogue on a lightly pre-structured basis. Responding to the agenda, needs and opportunities of the moment, we ground in unfolding experience and identify possible ways forward, together.

**Meeting formats for shared practice**

The following paragraphs present short descriptions of the meeting formats that we have practised with the Mindful Researchers (modified and extended from, Mindful Researchers, 2022):

*Listening Circle*: A Listening Circle (Linnea & Baldwin, 2010; Bohm, 2004) - also referred to as Council (Zimmermann & Coyle, 2009) - is an intentional space to share experiences. The practice is based on the ancient tradition of gathering around a fire to tell stories. It usually begins with a reminder of its form - there is a beginning, an end, a centre and a talking piece - and its principles: (1) to listen with one's whole self (at a conceptual/mental, emotional and physical/bodily level, as well as to the general atmosphere in the group), (2) to share stories from one's personal experience (instead of abstract ideas or explanation), (3) to wait before speaking until the essence of an experience has settled (to express the essence), (4) to share spontaneously, without too much planning or judgement, (5) to share something of service - to oneself, those present, and all others, and finally (6) to honour confidentiality - the agreement that we may harvest richly from our experience of a circle, but that the stories shared by others should remain theirs to share. After a reminder of these principles, the practice proceeds with a moment of grounding. It then opens up for anybody to voice intentions and dedications for this circle, and enters into sharing and witnessing of the stories that are present in the group. Listening Circles, or more simply the opportunity to hear voices and reflections, to digest and compost experience as a group, can be instances in which a whole group participates to set and shift their context and purpose (*modified description from* Lübbert et al, 2021). Wolfgang and myself have completed training for Listening Circle facilitation and are the regular facilitators. More recently, we have increasingly shared the facilitation with other Gardeners.

*Mindful Presentations*: After a short welcome, grounding and check-in, one or two researchers present their work, followed by group conversation in the spirit of a Listening Circle. Whenever appropriate we may invite a moment of pause to reconnect and ground with our embodied experience - such as after a contribution of any length that feels significant (it can be very short, even one word, or an expressed emotion), or when someone spoke very fast or intensely, to digest the momentum and energy. Different from the presentations we typically give to academic peers, these short talks (also) invite deeper reflections on why and how we care about or struggle with our research. The format includes the possibility and invitation to discuss non-academic resources, ventures and questions in life that matter to us.

Stepping deeper into our work or branching off into new directions can quickly involve uncertainty, which we welcome and learn to work (dance) with. With this format, we offer a simple space of support and curiosity for researchers to test-run reflections that depart from their typical style or the established discourse in their home-discipline. All Gardeners facilitate this form - there may also be external facilitators joining because of their special role in inviting the speaker or bringing about the event.

*Co-creation session*: In a series of co-creation meetings, we have explored shared note-taking as a means to harvest insights from an emergent group process. For instance, we have combined a listening circle format with online canvases to investigate the needs and interests of the larger community: how should the network of Mindful Researchers evolve, so that it aligns well with the concrete needs and possibilities envisioned by diverse individual and groups of researchers? What should be its core purpose(s)? We have also used this format to collect our experience - or imagined 'typical personae' - at conferences and other scientific gatherings, intending to learn more about the spaces people navigate there and what could be improved to support fruitful exchange. Most recently, we are engaged in a prolonged phase of reflection to integrate our (Gardeners) perspectives on the Mindful Researchers into a common ground and shared focus. Here, we invite individual sharing (on how we came to, are currently experiencing and envision our future engagement in the Mindful Researchers), take collective notes there-of, and offer individual reflections and presentations that integrate what we heard from everyone.

The co-creation session is an evolving format. Besides tools from our other meeting formats, we bring in elements of co-design (Simonsen & Robertson, 2013) and an empirical attitude: we reflect more consciously on methodology, gather data, document the process and trace developments over time. In short, we use this format to support co-creative organisational design with a contemplative attitude.

*Playful Academic session*: Based on my work with Katrin Heimann and Pedro Gonzàlez-Fernàndez (Lübbert et al, 2021; Epilogue 1 to this thesis), we have facilitated playful academic sessions in which participants are guided through a series of games (or scores). The sessions usually begin with a fun and simple improvisation game, individual exploration (e.g. of space, embodied awareness, our reading or writing habits) and break-out sessions in pairs to ease into interaction. This involves prompts for reflection and dialogue about our intentions and motivation for our work, as well as simple joint improvisation games. Later, we moved to sharing and/or scores that involved the entire group of participants. Overall, the sessions provide a light and easy way to open work habits to nearby areas of possibility: what happens when I stay aware of bodily sensations (e.g. in the lower back or feet), as I read or write this text - does anything shift? What comes up in my experience - which images, memories, imagined personae or scenarios - as I listen to this sentence or paragraph? When I follow someone else's movements, find a rhythm with them, complement or complete an action they performed - where does that take us, what do we come to speak about or create together? Be it in thought, writing or interaction, the idea of a playful academic session is to practice different modes of attending and exploring, to become aware of the opportunities that are available through (small) shifts in the frame through which we approach our work.

*Open discussion*: In this meeting format, the structure and flow is more emergent. After our usual grounding and check-in, we move to an open conversation (a continuation of sharing rounds). These meetings are gently facilitated open spaces for welcoming new members, reconnecting with each other, and engaging in open conversation on questions or themes brought on by participants. The facilitators may also offer a prompt to elicit conversation around a timely or ongoing theme.

**Curiosity about and sensitivity towards shared space**

Our initiative involves cross-disciplinary researchers (and other professionals) in both shorter- and longer-term participatory processes. As evident from the descriptions of our meeting formats, we emphasise the ability (opportunity) to pause and notice what is present within and around us (thoughts, bodily sensations, social & physical environment). We also invite participants to voice what is going on in their experience and diverse life backgrounds. Through structured formats such as the Listening Circle, we recruit (strengthen) the capacity of the group to listen and offer sensitive support - that is, with openness to difference and by collectively defining what is important: in a Listening Circle, stories are offered *from experience* in response to collectively set intentions and inclusive prompts. In general, the group learns to make space for what appears most important in the present meeting and moment. This presents both challenge and opportunity: it confronts us with the tensions and creative potential inherent to the group. Since the group process requires ongoing participatory sense-making, careful attention and trust in the possibility to express (be heard) and listen are vital ingredients.

Our approach fits well with the enactive ethics described by Di Paolo and De Jaegher (2021), which focuses on the potential for fruitful participation that is inherent in differences. We have come to notice (especially during our recent in-person meeting among the Gardeners group) that the structural and collective support we offer to listening (and letting be, De Jaegher, 2021) can help us become aware of our biases. Varela's (1999) advocacy for inquiry into first person awareness makes a related point: as he argued, methodological inquiry into first person awareness could provide the natural sciences with a "needed ground, for all knowledge necessarily emerges from our lived experience" (ibid, p.336). In other words, given that concepts become accessible (affordable, useful) from within, access to a fuller range of experience affords deeper insight and understanding of conceptual implications and possibilities. Often, however, cognitive-affective reflexes can bias our perception and behaviour. The space we cultivate with the Mindful Researchers initiative has the potential to enhance our sensitivity to such subtle (or buried), often unnoticed dimensions of experience (Maturana & Varela, 1992; Varela, Thompson, & Rosch, 1991; Thompson, 2007; Rees, 2019). As such, we find that sustained engagement in our practice may support more grounded and thorough scientific inquiry and work.

Beyond positive effects on individual well-being, strength of character and scientific ability, we believe that our work welcomes, calls and prepares us for wider systemic change: through regular engagement in rigorous practice and co-created projects, including the discovery of what is most important for us to address, we may generate more sustainable research projects and academic trajectories in the long run (Brette, 2020; Woolston, 2020; Joynson & Leyser, 2015). In particular, this concerns a way of working that is grounded in a spirit of curiosity and mutual offering, as well as research themes and questions that are formulated by a collective - through ongoing, playful exploration of what we find most helpful and inspiring.

After our group reflection process and (first) physical meeting in late March 2022, we are now focused on research interests and availabilities for shared commitment. Meeting in person was a vital opportunity to get to know each other better, deepen our practice and reflect on our resources, plans and vision: we took longer times to ground, Mary guided us into a series of insight dialogue sessions, I offered short movement sessions, and we clarified organisational, practice and research matters in afternoon sessions (usually structured as a Listening Circle). Besides formulating guiding principles, writing down reflections on our practice, and planning our next physical gathering (fall 2022), we decided to commit more time to our work and practice together, continue the regular Mindful Researchers events with the wider community, and pursue pilot research projects (through interviews and individual writing projects) that could be expanded into interdisciplinary research projects to be carried out in collaboration with researchers and participants from our individual networks and the wider Mindful Researchers community.

**Personal conclusion: completed projects and ongoing lines of work**

I feel inspired and well-vested by our continued process of shared investigation. Besides my sustained participation in the Gardener's group and my role as a facilitator in Mindful Researchers events, I participated in several external projects linked to our work as Mindful Researchers: together with Wolfgang, Francesco, Mary, Willeke and Enrico, I co-facilitated a three-session workshop (conference track) at the 2021 European Summer Research Institute (ESRI, organised by Mind & Life Europe). Together with Mary, Willeke and Wolfgang, I furthermore held a symposium at the 2021 APA convention, titled *Recognizing and Enhancing Enactive Awareness in Science, Research, and Academia*. I am also part of a team led by Marieke van Vugt (that includes Enrico, Mary and Wolfgang, as well as Frank Schumann, Mareike Smolka and Zoltan Dienes), with whom we are preparing to submit a manuscript on the theme of a more collegial and values-based scientific practice and organisation. Finally, together with Wolfgang and Laura Candiotto, I am co-chair of the planning committee for the upcoming ESRI conference, titled *Learning with Others - Living Connection and Transmission*. The conference takes place in August 2022 at a renown Buddhist centre in Pomaia, close to Pisa, Italy.

The fruits of our work as Mindful Researchers are plenty - I am excited to continue this line of work in 2022 and beyond. I look forward in particular to manifesting what we learned over the course of our 'deep dive' about shared (and distinct) views and aspirations among the Gardeners team. Another highlight is being centrally involved in the organisation of ESRI 2022. It provides an exciting opportunity to implement what I learned over the course of my PhD. In particular, with the planning committee and core team of invited contributors, we are preparing a program that brings diverse approaches to learning and traditions of knowledge together, to be inspired and learn from the questions and backgrounds of experience and expertise brought in by all participants.

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Besides myself, the currently active core team of Gardeners consists of:

- Wolfgang Lukas (Graz, AT), PhD in physics, supporting collaborative science communities;
- Mary Rees (Houston TX, USA), PhD in psychology and interdisciplinary inquiry, strengthening integrity and ethics through contemplative awareness;
- Enrico Fucci (Canary Islands, ES), PhD in neuroscience, IGDORE board member, building structural support for a rigorous science of openness and integrity;
- Willeke Rietdijk (Amsterdam, NL), PhD in education, exploring the mind in meditative processes;

- Francesco Michele Noera (Milan, IT), anthropologist, promoting co-design and co-creative tools in academia and beyond; and
- Nikola Winter (Vienna, AT), PhD in molecular biology, asking "What is life?" / "What is aliveness?" / "How does it all work together?".

As Mindful Researchers, we have explored principles of embodied and enactive cognition beyond the classical cognitive science laboratory: together, we developed and tested tools, posed research questions to sharpen and reflect our practice, shared methods and identified modes of meeting, collaborating and organising that can support our work in the future. I feel lucky to have found a group of researchers who value lived experience, practice and exploration just as much as rigorous study, reflection and analysis.

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Without **Andreas K. Engel**, director of the Department of Neuro- and Pathophysiology, and supervisor to my doctoral thesis, I would have neither joined the department, nor been able to work on my thesis as independently and for as long as I did. Andreas placed two sub-projects of a large European research consortium under my responsibility. Working on what turned out to be the BallGame and MirrorGame paradigms as part of our larger research team taught me about the ingredients and lifetime of a large scale research project: from conceptual work, study design, data analysis, interpretation and publication, to interdisciplinary collaboration, follow-up grant applications, as well as the reports and meetings that form part of a European Union grant revision process. Andreas also endorsed my development as an independent researcher: besides my participation in conferences and skills training, I was able to spend research visits in Aarhus at the Interacting Minds Centre (IMC) and in Paris at the Institut Pasteur, and - through the support of the Varela award - realise independent work (the in-depth subjective experience assessment in the Sonified MirrorGame, as well as the Playful Academic).

**Florian Göschl**, post-doctoral research fellow at the Department of Neuro- and Pathophysiology with a background in psychology and neuroscience, was my closest and indispensable collaborator from the beginning to the end of the PhD. Together, we developed the BallGame, prepared the lab space for the complicated hyper-scanning setup, conducted the experiments and - in particular - designed the comprehensive framework of analysis that integrates multiple of the qualitative and quantitative methods of observation used in the BallGame. Florian has been a colleague, advisor as well as friend - our collaboration involved countless walks around the UKE campus and extended bike-rides through the vicinity of Hamburg. Our back and forth - verbally, in code and on paper - provided the training and motivation I needed to complete this PhD.

**Lissa Streeter**, Paris-based artist, accompanied and guided me through the most difficult (and exciting) phases of my PhD. She compelled me to find the support, feedback and collaborative spaces I needed to develop and pursue my research questions, and taught me about the immediate ways in which materials, tools, social and physical environments can be tremendous resources for co-creative expression and discovery. Lissa opened my eyes to the importance of doing work that presents curated but open-ended invitations to explore and participate.

**Joe Dumit**, professor of anthropology and science and technology studies at UC Davis with a large and inter-disciplinary network of research connections in Europe and USA, widened my sense of what is possible. His deep understanding of the workings of academic disciplines, and in particular his stories of initiatives and researchers who created opportunities for curious, joyful, serious exploration inspire(d) me to simply try, find like-minded others, develop a research practice together and share what we learn with others. His focus on (researchers') passions continuously reminds me to look for open doors, support what is available and interesting, and interact with strange others as portals to a different world (view). Joe provided essential feedback, inspiration and opportunity to exchange throughout the final months of my thesis writing.

**Andreas Roepstorff**, director of the IMC, and head of the School of Culture and Society at Aarhus University, listened and provided feedback when it mattered, encouraged me to apply for independent funds to develop the research tools that I needed, and - through IMC - connected me with a whole network of scientists deeply invested in my topic of research: interacting minds (and bodies)!

**Katrin Heimann**, associate professor at IMC, became a close collaborator during the Playful Academic project. When Katrin joined the project (originally intended for reflection on the methods I used in the Sonified MirrorGame), our conversation quickly moved the project towards 'practicing what we preach' as 4EA scientists: together with Pedro, we then developed a set of scores to bring embodied awareness and playful, improvised modes of interaction into collaborative research. Katrin's clear understanding of research as intervention inspires me - our (ongoing) collaborations are marked by the desire to enliven academic discourse through research methods and forms of dissemination that integrate the researcher, the research process and its context.

**Pedro González-Fernández**, PhD candidate in modern composition, joined me in the early stages of my second experimental PhD project: the Sonified MirrorGame. To develop the paradigm and protocol, we spent hours conversing and debating the topic of engaged co-creative interaction as well as the kind of environment that might best facilitate it. Pedro's experience as a musician, composer and improvisation teacher was a corner stone in our development of the scores for the Playful Academic. It was Pedro who got me interested in the modern dance form contact improvisation - and told me about the places in Hamburg where I could go and explore.

**Lior Noy**, lecturer in cognitive science and business who studies creative exploration through minimal settings like mirror games, provided invaluable feedback to drafts of Chapter 4 as well as the thesis frame. Lior's poignant comments and suggestions helped me improve the chapter on the Sonified MirrorGame, and clarify the different voices or perspectives from which I speak about my work, as well as the structure of my entire thesis.

Finally, I want to mention **Frank Schumann**, **Dav Clark**, **Wolfgang Lukas** and the core members of the Mindful Researchers initiative: Wolfgang, as well as **Mary Rees**, **Enrico Fucci**, **Willeke Rietdijk**, **Francesco Michele Noera** and **Nikola Winter**. All of them - individually and as groups - provide(d) support and space for collaborative reflection and practice, essential ingredients for my development as a researcher. The shared commitment of the Mindful Researchers to a more embodied and relational research practice presents rich challenges and endless(ly rewarding) learning experiences. I am time and again surprised and convinced by our ability to continue to discover and 'lay our path down in walking'.

It was exciting to learn about social interaction dynamics from a variety of perspectives - beginning in a literature review of concepts such as sensorimotor contingencies, participatory sense-making and embodied and enactive cognition more generally, I got involved in practices that guide our attention to the body in interaction with others and the environment. In both domains, I learned about continuously unfolding dynamics of mutual influence between self, other and environment. While the theoretical background of my work is introduced in detail in Chapters 1 and 2 of this thesis, I would here like to acknowledge the practices - and meeting groups for regular practice - that had major influence on my work: **contact improvisation** and other forms of somatic practice, generic contemplative practices / mindfulness, the **micro-phenomenological interview technique**, and the meeting format of a **Listening Circle**. These practices taught me about the vast potential inherent in grounding experience through attention that notices and opens up (relaxes) bodily sensations. Beyond dedicated times and spaces for practice, I learned to create moments of pause to relax into small movements or sounds, listen more fully and respond more intuitively to my experience - as I walk down a sideway, run an experiment, facilitate a group conversation or interact with a friend, colleague or stranger. The knowledge transmitted through these techniques fits remarkably well with concepts I had learned about in scientific literature. Resembling the emphasis that concepts of embodied and enactive cognition place on participation and dynamics of mutual influence, these forms of practice continue to expand my toolbox for attending and orienting in the moment by asking, 'what is present? What is available, valuable and interesting in this situation?'.

(Practical) Knowledge thrives on (shared) practice: integrating lessons from these (and other) practices in my work and life (such as through the projects I present in the epilogue) would not have been think- or doable without longer and short-term collaborations I engaged in with researchers in and outside of academia. I therefore trace another important line of support and inspiration for my doctoral research back to my attendance at the Mind & Life conference (European Summer Research Institute - ESRI) in August 2017. Here, I met researchers with whom I collaborate and exchange ever since (in particular Joe Dumit and Terje Sparby), and got a more personal impression of Francisco Varela's approach to science: a weaving together of personal practice and rigorous research. The event (together with Andreas Roepstorff's encouragement both at and after ESRI) convinced me to apply for the Varela award, that is, for support to create the tools I needed to do the research I wanted to do. In the months and years to come, I then got involved in diverse **collaborative projects** to reflect and explore concepts and practices of embodied and participatory sense-making: per chance (sympathy), I followed Lissa Streeter's invitation to join an inspiring reading group that met irregularly for dialogue and practice (in Paris), started to read feminist philosophy of science (Haraway, Despret, Myers, Gagliano), and began to team up with friends and colleagues to form research groups for regular exchange and practice. These connections provided important spaces for reflection and development, and enabled me to progressively integrate my personal practice as a researcher with the theoretical insights and practical tools I had gathered. While some groups consisted of regular online conversations, others involved shared movement practice - yet others both. In the following, I shortly introduce several of these projects:

**Project 1, The spiral - a model and toolbox**: In February 2019, I sketched my perspective on research and development as a personal process in the form of a spiral. It captures the opportunity (I see) in difficult moments ('triggers') to sense and act towards that which is needed and/or interesting (important desires). I learned much of this in my close relationships, over time weaving in insights about sensorimotor contingencies, 4E cognition and embodied practice. The model sketches prototypical stages of a process from 'trigger' to 'curiosity and invitations to explore', and presents tools to encourage transitions into and between them: individual and interactive examples of mental as well as embodied practice that can strengthen our ability to listen and express. It continues to serve as the basis for how I practice and facilitate.

**Project 2, Workshops on 'Sensing into 4E Cognition'**: In collaborations with somatic practitioner Erin Bell and artist Lissa Streeter, I contributed to or offered five workshops that involved moving back and forth between verbal exchange and movement/awareness practice. The sessions (hosted in Paris, Berlin and Ljubljana) invited participants to curious exploration and reflection of their experience in individual, duo or group practice, and aimed to create links between contemplative somatic practice and cognitive science research.

**Project 3, Articulating somatic communication**: Invited by Angela-Mara Florant (contact improvisation teacher), I joined a Hamburg-based group of dancers and performers to study somatic communication. Together with Angela-Mara and Natasha Golubtsova, (as well as Dagmar Bock, Lara Bogotaj, Theresa Hoffmann and Nita Little), we met irregularly to articulate and train embodied attention skills. Initially guided by Nita Little (and her global initiative - ISSC), our work soon became independent. Besides moving together, we used writing, discussion (sharing circle), and micro-phenomenological interviews to reflect on our movement practice.

**Project 4, Enactivist meetings for Contemplative Scientific Collaboration**: In weekly online meetings with Frank Schumann, Wolfgang Lukas, and Dav Clark (as well as several visitors), we shared, reflected and gave feedback on our ongoing work, news and developments concerning contemplative / 4E collaboration in and outside of academia, with an open ear for personal questions, struggles and intuitions.

**Project 5, Research visits to the Interacting Minds Center (IMC), Aarhus University**. In short and extended visits to the IMC, as well as online meetings, I developed extended ties to the IMC. In particular, I attended workshops on embodied creativity and EEG-hyperscanning, joined 'Open-Your-Data-sessions', assisted the research around the 'Horse inside out' installation (part of a large art-science collaboration lead by Olafur Eliasson and Andreas Roepstorff - *Experimenting, Experiencing, Reflecting*), and entered long-term collaborative exchange with Katrin Heimann and Mihaela Taranu.

Besides these ties to fellow researchers, I want to thank my **family and home** - Christa, Klaus, Nele and Felix, as well as Gerrit Braun and the entire Braun family (Micky, Johanna, Greta and

Keke, as well as Basti, Jona, Noah and David). You inspired my sense of what is important and possible, and nurtured my creativity and sturdy will. Marcus Frey also deserves mention: his fierce and calm joy and independence challenged me to walk my path with openness, pleasure and sensitivity for what is needed. These qualities lie at the heart of how I engage in science. Together with Gudrun and Rüdiger Rohde, my parents furthermore provided a space where I could retreat and write, take walks and bathe in the Northern Sea: **Amrum**. Many words of this thesis were written there. Inspired and assisted by my adventurous friend Tamina Florentine Zuch, I further built myself a garden house. The garden (a lot at the *Kleingarten Horner Marsch*, Hamburg) is a shared project with my brother Felix. It provides another space for me to dig into soil and build ground (literally), as well as to retreat, exert and gather myself physically.

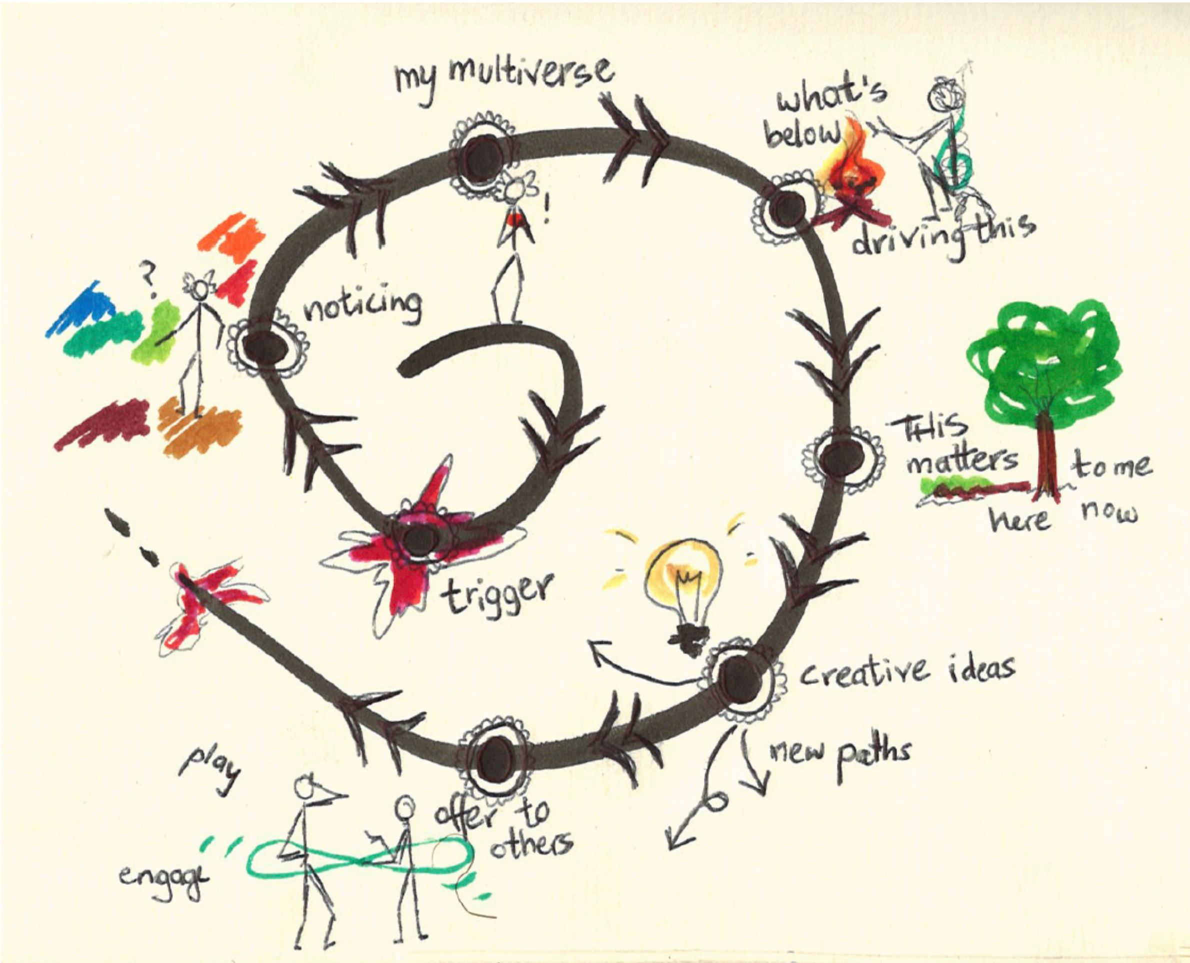



**Figure Ac1** Project 1: The spiral - a model and toolbox to navigate interpersonal dynamics. Original draft created during my visit to Lissa Streeter, Paris, February 2019.

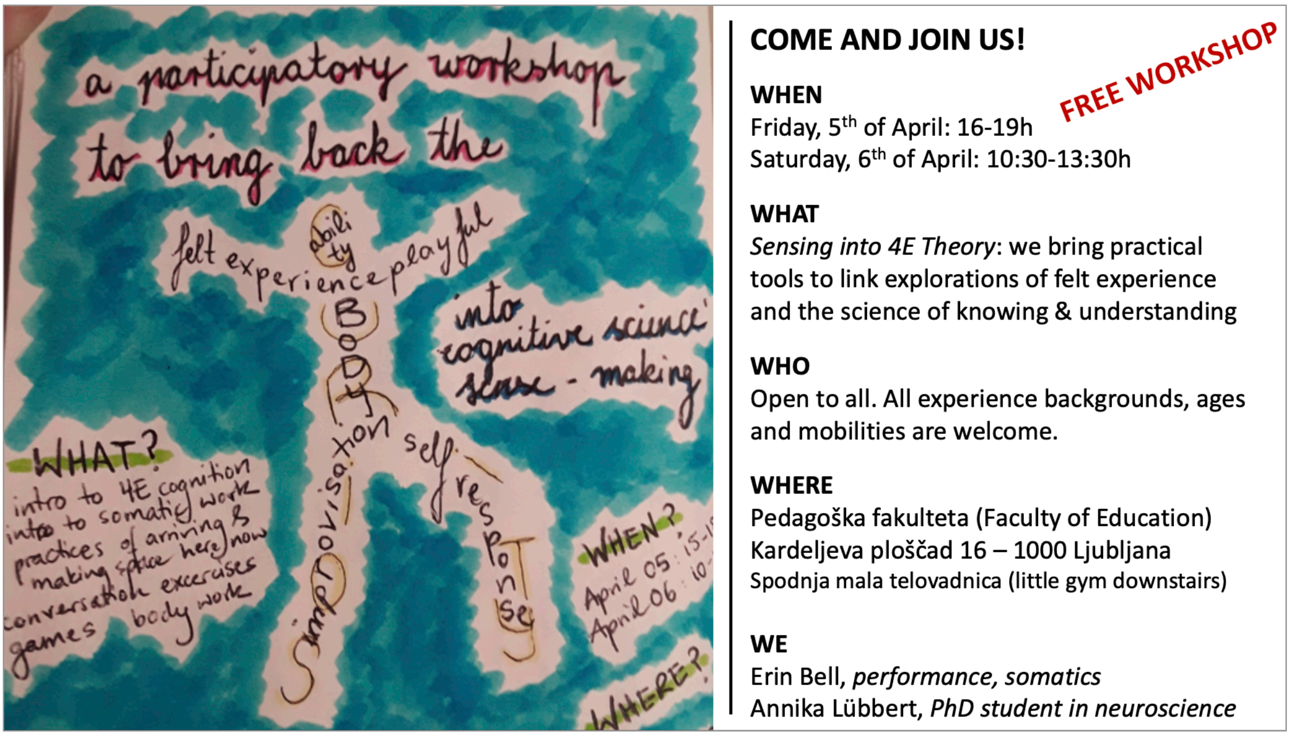



**Figure Ac2** Project 2: Invitation to a workshop to bridge somatic practice with theories of embodied / 4E cognition. Co-organised by Erin Bell and myself in Ljubljana, Slovenia, April 2019.

# APPENDIX I

## Supplementary Materials for Chapter 3, the BallGame

A. *Movement coordination measures*
B. *Initial and final Linear Mixed Effects Models*
C. *Statistics for MANOVAs and Post-hoc ANOVAs, as well as pair-wise comparisons between individual block- and trial steps*
D. *Significant (as well as trends towards) main effects and two-way interactions from the ANOVA over sessions, conditions and block steps*
E. *Significant (as well as trends towards) main effects from the ANOVA over trial steps*
F. *Participant Interview*
G. *Thematic content analysis*

## Supplementary Materials I.A

### Movement coordination measures

***Windowed-lagged cross-correlation****:* In line with a recent validation study (Schoenherr et al, 2019), as well as our own tests with a range of parameter settings, we settled on windows of 3.6 seconds (220 frames) and a window overlap of 3.3 seconds (200 frames), leading to a step-size of 0.3 seconds. We further assessed correlation between players' movements at interpersonal lags of up to 1.1 seconds (70 frames) with single frame increments (60 Hz resolution, i.e. 0.017 seconds). In other words, we assessed correlation across 141 lags (70 lags player one leads, 70 lags player two leads, 1 lag simultaneous movement) at 157 time points during each trial. In other words, we assume that events last approximately 3.6 seconds, that the evolution of players' interactions can be observed at a resolution of 0.3 seconds, and that inter-player coordination does not exceed a delay of 1.1 seconds and can be observed at a resolution of 0.017 seconds.
***Peak-picking****:* To identify potential leading or lagging between players at each of the 157 time steps, we identified the lag between players' steering directions that showed the strongest correlation above a minimum of 0.3 that was closest to simultaneous movement (0 lag). Since we set time steps at which the maximal correlation coefficient over all lags is lower than 0.3 to zero, our ppWLCC parameters indicate coordination over short, intermittent periods of time
***Mutual Information****:* Using custom-made scripts based on Cohen (2014), we calculated MI values for each block step, that is, in parallel with moments of experience rating in the experiment. A block step comprises three or four trials. Accordingly, we calculated MI for durations of 180 or 240 seconds, as well as for each session, condition and pair. The number of bins to discretise the data was estimated using the Freedman-Diaconis rule (Freedman & Diaconis, 1981). As the number of bins influences the entropy estimate, we first estimated the optimal bin number for each pair, session, condition, and block step. Then, we took the ceiling of the grand average of the optimal bin number (25 in our data set) and re-ran the whole analysis with 25 bins for every calculation. In order to derive standard statistical Z-values of our MI estimates, we additionally applied

permutation statistics. In 500 iterations, we temporally shifted one of the two time series by some random factor and calculated MI, to finally create a distribution of MI values expected under the null hypothesis from which Z-values were derived (again compare Cohen, 2014). These Z-values (one for every pair, session, condition, and block step) were then subjected to statistical comparisons.

***Phase-slope-index***: As for MI, we aggregated data at the level of the block step. We estimated PSI (using data2psi.m, METH toolbox, Guido Nolte) for segment lengths ranging from 20 samples (0.333 seconds at a sampling rate of 60 Hz) to 240 samples (4 seconds) in steps of 20 samples (0.333 seconds) but for further analysis, we selected PSI values calculated using a time window of 40 samples (0.667 seconds). This choice was motivated by systematical assessment of the parameter space in an initial analysis step with the goal of finding the segment length that maximises the mean normalised PSI (calculation of the standard deviation across epochs using the jackknife method was done with different epoch lengths of 2, 3, and 4 seconds) across pairs, sessions, conditions, and block steps. What is more, PSI was calculated across all frequencies (wide band) based upon visual inspection of the grand average power spectra, where no apparent frequency peaks nor differences between conditions were present.

**Supplementary Materials I.B**

**Initial and final Linear Mixed Effects Models**

*Engagement*

| ***Initial*** **Predictor of engagement** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **1.193** | **0.049** | **24.207** | **0.000** |
| Autoregressive covariance | 0.022 | 0.069 | 0.324 | 0.748 |
| **Trial (time)** | **-0.026** | **0.004** | **-6.950** | **0.000** |
| **Condition (same vs diff)** | **-0.025** | **0.012** | **-2.022** | **0.044** |
| Neuroticism differences | 0.036 | 0.042 | 0.856 | 0.401 |
| **Extraversion differences** | **-0.092** | **0.041** | **-2.269** | **0.034** |
| Openness differences | 0.002 | 0.040 | 0.049 | 0.961 |
| Agreeableness differences | 0.024 | 0.044 | 0.529 | 0.602 |
| Conscientiousness differences | -0.010 | 0.041 | -0.242 | 0.811 |
| Autism quotient differences | -0.008 | 0.043 | -0.183 | 0.857 |
| Empathy differences | -0.064 | 0.039 | -1.630 | 0.117 |
| Distance covered by finger moves | 0.048 | 0.030 | 1.584 | 0.114 |
| Number of finger moves | -0.019 | 0.022 | -0.860 | 0.391 |
| Synchrony (WLCC-coef-mean) | 0.038 | 0.022 | 1.738 | 0.083 |
| Strength of relation (ppWLCC-coef-mean) | -0.027 | 0.028 | -0.974 | 0.331 |
| **Stability of relation (ppWLCC-coef-std)** | **0.037** | **0.012** | **2.959** | **0.003** |
| Time-lag (ppWLCC-lag-mean) | -0.012 | 0.021 | -0.582 | 0.561 |
| Switching (ppWLCC-lag-std) | -0.012 | 0.014 | -0.845 | 0.399 |
| Mutual information | 0.016 | 0.015 | 1.074 | 0.284 |
| Phase-slope index | 0.008 | 0.013 | 0.580 | 0.563 |
| **Number of targets** | **0.094** | **0.033** | **2.826** | **0.005** |
| Target sequence complexity | 0.029 | 0.022 | 1.346 | 0.179 |
| Time on obstacles | 0.004 | 0.032 | 0.123 | 0.902 |
| **Total path length** | **-0.070** | **0.035** | **-2.004** | **0.046** |

| ***Final*** **Predictor of engagement** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 1.199 | 0.055 | 21.703 | 0.000 |
| Autoregressive covariance | 0.021 | 0.069 | 0.311 | 0.760 |
| Trial (time) | -0.027 | 0.004 | -7.260 | 0.000 |
| Condition (same vs diff) | -0.023 | 0.011 | -2.213 | 0.028 |
| Stability of relation | 0.031 | 0.014 | 2.178 | 0.030 |
| Number of targets | 0.029 | 0.012 | 2.397 | 0.017 |
| Total path length | 0.109 | 0.029 | 3.710 | 0.000 |

| ***Final*** **Random effects engagement** | **variance** | **std. dev** | **corr** |
|---|---|---|---|
| Pair intercept | 0.05414 | 0.2317 | |
| Autoregressive covariance | 0.02112 | 0.1453 | -0.87 |
| Residual | 0.02660 | 0.1631 | |
| Number of observations: 275 | Number of pairs: 23 | | |

*Agreement*

| ***Initial*** **Predictor of agreement** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **0.722** | **0.024** | **30.602** | **0.000** |
| Autoregressive covariance | -0.113 | 0.070 | -1.613 | 0.133 |
| Trial (time) | -0.001 | 0.002 | -0.503 | 0.615 |
| Condition (same vs diff) | 0.005 | 0.008 | 0.619 | 0.537 |
| Neuroticism differences | 0.024 | 0.021 | 1.139 | 0.266 |
| **Extraversion differences** | **-0.045** | **0.021** | **-2.173** | **0.041** |
| Openness differences | 0.009 | 0.020 | 0.452 | 0.655 |
| Agreeableness differences | 0.017 | 0.023 | 0.748 | 0.462 |
| Conscientiousness differences | -0.019 | 0.020 | -0.937 | 0.358 |
| Autism quotient differences | 0.036 | 0.021 | 1.681 | 0.106 |
| Empathy differences | 0.016 | 0.020 | 0.805 | 0.429 |
| Distance covered by finger moves | 0.004 | 0.019 | 0.196 | 0.845 |
| Number of finger moves | 0.005 | 0.014 | 0.321 | 0.749 |
| Synchrony (WLCC-coef-mean) | -0.004 | 0.014 | -0.310 | 0.757 |
| Strength of relation (ppWLCC-coef-mean) | 0.005 | 0.018 | 0.295 | 0.769 |
| **Stability of relation (ppWLCC-coef-std)** | **0.015** | **0.008** | **1.885** | **0.061** |
| Time-lag (ppWLCC-lag-mean) | -0.011 | 0.013 | -0.802 | 0.424 |
| Switching (ppWLCC-lag-std) | 0.006 | 0.009 | 0.697 | 0.486 |
| Mutual information | 0.011 | 0.009 | 1.219 | 0.224 |
| Phase-slope index | -0.001 | 0.008 | -0.103 | 0.918 |
| **Number of targets** | **0.045** | **0.020** | **2.193** | **0.029** |
| Target sequence complexity | -0.014 | 0.013 | -1.026 | 0.306 |
| Time on obstacles | 0.006 | 0.020 | 0.316 | 0.752 |
| **Total path length** | **0.036** | **0.022** | **1.621** | **0.106** |

| ***Final*** **Predictor of agreement** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 0.715 | 0.024 | 30.124 | 0.000 |
| Autoregressive covariance | -0.129 | 0.073 | -1.777 | 0.101 |
| Extraversion differences | -0.050 | 0.023 | -2.194 | 0.041 |
| Stability of relation | 0.015 | 0.007 | 1.971 | 0.050 |
| Number of targets | 0.059 | 0.016 | 3.704 | 0.000 |
| Total path length | 0.033 | 0.013 | 2.532 | 0.012 |

| ***Final*** **Random effects agreement** | **variance** | **std. dev** | **corr** |
|---|---|---|---|
| Pair intercept | 0.01208 | 0.1099 | |
| Autoregressive covariance | 0.04320 | 0.2078 | 0.46 |
| Residual | 0.01043 | 0.1021 | |
| Number of observations: 275 | Number of pairs: 23 | | |

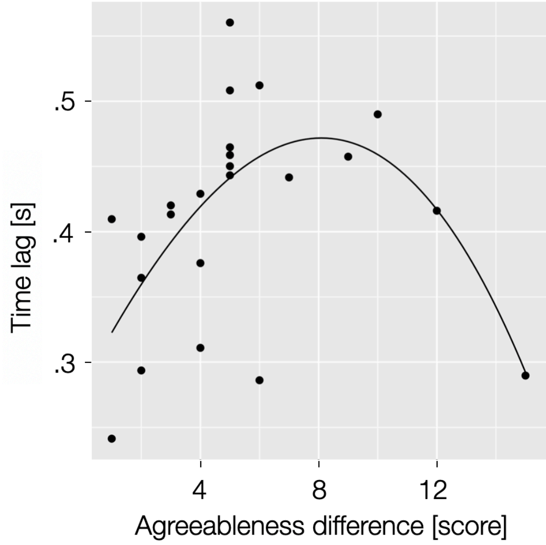
*Predictability*

| ***Initial*** **Predictor of predictability** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **0.738** | **0.026** | **28.611** | **0.000** |
| Autoregressive covariance | -0.046 | 0.074 | -0.624 | 0.543 |
| Trial (time) | 0.000 | 0.002 | -0.245 | 0.807 |
| Condition (same vs diff) | 0.003 | 0.007 | 0.465 | 0.643 |
| Neuroticism differences | 0.014 | 0.019 | 0.761 | 0.455 |
| Extraversion differences | -0.028 | 0.019 | -1.453 | 0.160 |
| Openness differences | 0.026 | 0.019 | 1.413 | 0.171 |
| **Agreeableness differences** | **0.037** | **0.021** | **1.793** | **0.085** |
| **Conscientiousness differences** | **-0.036** | **0.018** | **-1.952** | **0.063** |
| Autism quotient differences | 0.029 | 0.020 | 1.477 | 0.153 |
| Empathy differences | 0.001 | 0.018 | 0.064 | 0.950 |
| Distance covered by finger moves | 0.005 | 0.018 | 0.267 | 0.789 |
| Number of finger moves | -0.001 | 0.013 | -0.069 | 0.945 |
| Synchrony (WLCC-coef-mean) | 0.002 | 0.013 | 0.132 | 0.895 |
| Strength of relation (ppWLCC-coef-mean) | 0.005 | 0.016 | 0.286 | 0.775 |
| **Stability of relation (ppWLCC-coef-std)** | **0.017** | **0.007** | **2.420** | **0.016** |
| Time-lag (ppWLCC-lag-mean) | -0.009 | 0.012 | -0.767 | 0.444 |
| Switching (ppWLCC-lag-std) | 0.000 | 0.008 | -0.020 | 0.984 |
| Mutual information | 0.002 | 0.003 | 0.682 | 0.496 |
| Phase-slope index | -0.226 | 0.302 | -0.747 | 0.456 |
| **Number of targets** | **0.049** | **0.018** | **2.713** | **0.007** |
| Target sequence complexity | -0.017 | 0.012 | -1.401 | 0.162 |
| Time on obstacles | -0.020 | 0.018 | -1.092 | 0.276 |
| Total path length | 0.000 | 0.020 | 0.018 | 0.986 |

| ***Final*** **Predictor of predictability** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 0.741 | 0.019 | 38.637 | 0.000 |
| Autoregressive covariance | -0.038 | 0.076 | -0.493 | 0.630 |
| Agreeable differences | 0.047 | 0.019 | 2.424 | 0.024 |
| Conscientious differences | -0.040 | 0.019 | -2.087 | 0.049 |
| Stability of relation | 0.016 | 0.007 | 2.363 | 0.019 |
| Number of targets | 0.066 | 0.011 | 5.784 | 0.000 |
| Time on obstacles | -0.021 | 0.010 | -2.088 | 0.038 |

| ***Final*** **Random effects predictability** | **variance** | **std. dev** | **corr** |
|---|---|---|---|
| Pair intercept | 0.007763 | 0.08811 | |
| Autoregressive covariance | 0.054269 | 0.23296 | 0.21 |
| Residual | 0.008413 | 0.09172 | |
| Number of observations: 275 | Number of pairs: 23 | | |

**Figure A.I.1** Relation between interpersonal time lag and agreeableness differences between players. The plot shows mean values of interpersonal time lag across all joint play trials, as well as the difference in the NEO-FFI agreeableness score between players. The line indicates a third order polynomial fit through the data.




**Supplementary Materials I.C**

**Statistics for MANOVAs, individual measure ANOVAs, as well as post-hoc pairwise comparisons between individual block- and trial steps**

**Tables A.I.1** MANOVAs and Post hoc ANOVAs - main and two-way interaction effects. All p-values are FDR corrected at the MANOVA level, as well as within each family at the ANOVA level (here shown in separate tables). Significance levels are additionally indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10). The three-way interaction effect is not included in this table: all p > .18 and all MATS/ATS < 1.8.

| *MANOVAs* | Session | Condition | Block step | Session by condition | Session by block step | Condition by block step |
|---|---|---|---|---|---|---|
| **Experience** | + p = .076, MATS = 13.93 | p = .153, MATS = 4.92 | **** p = .009, MATS = 10.09** | p = .754, MATS = .54 | p = .244, MATS = 4.01 | p = .238, MATS = 3.76 |
| **Gaming behaviour** | **** p = .009, MATS = 33.02** | + p = .087, MATS = 7.91 | ***** p < .001, MATS = 17.01** | p = .570, MATS = 1.25 | p = .378, MATS = 3.08 | p = .338, MATS = 3.74 |
| **Basic movement** | p = .509, MATS = .88 | p = .971, MATS = .02 | + p = .087, MATS = 3.51 | p = .461, MATS = .63 | p = .461, MATS = 1 | p = .813, MATS = .20 |
| **Movement coordination** | **** p = .006, MATS = 35.82** | ***** p < .001, MATS = 97.5** | p = .101, MATS = 20.06 | p = .143, MATS = 7.25 | p = .334, MATS = 12.8 | p = .207, MATS = 17.8 |

| *post hoc ANOVAs Exp* | Session | Condition | Block step | Session by condition | Session by block step | Condition by block step |
|---|---|---|---|---|---|---|
| **Engagement** | + p = .054, ATS = 8.39 | p = .521, ATS = .63 | *** p = .017, ATS = 8.68** | p = .529, ATS = .54 | p = .975, ATS = .03 | p = .443, ATS = 1.25 |
| **Agreement** | p = .279, ATS = 2.15 | + p = .053, ATS = 6.51 | + p = .053, ATS = 5.76 | p = .523, ATS = .64 | p = .542, ATS = .72 | p = .446, ATS = 1.08 |
| **Predictability** | p = .159, ATS = 3.59 | p = .229, ATS = 2.44 | p = .156, ATS = 2.74 | p = .672, ATS = .27 | + p = .053, ATS = 4.92 | + p = .084, ATS = 3.98 |

| *post hoc ANOVAs Gam* | Session | Condition | Block step | Session by condition | Session by block step | Condition by block step |
|---|---|---|---|---|---|---|
| **Targets** | ***** p < .001, ATS = 29.15** | *** p = .030, ATS = 6.81** | **** p = .003, ATS = 8.43** | p = .877, ATS = .03 | p = .478, ATS = 1.03 | p = .569, ATS = .67 |
| **Obstacle time** | *** p = .024, ATS = 7.17** | *** p = .046, ATS = 5.90** | **** p = .005, ATS = 9.08** | p = .569, ATS = .55 | p = .406, ATS = 1.25 | p = .242, ATS = 2.03 |
| **Path length** | **** p = .008, ATS = 10.30** | p = .559, ATS = .64 | ***** p < .001, ATS = 13.91** | p = .329, ATS = 1.46 | p = .451, ATS = 1.20 | p = .654, ATS = .49 |
| **Complexity** | p = .180, ATS = 2.77 | p = .520, ATS = .75 | p = .172, ATS = 2.32 | p = .983, ATS = 0 | p = .242, ATS = 2.03 | + p = .079, ATS = 3.75 |

| *post hoc ANOVAs Mov* | Session | Condition | Block step | Session by condition | Session by block step | Condition by block step |
|---|---|---|---|---|---|---|
| **Number of moves** | p = .601, ATS = .61 | p = .914, ATS = .01 | + p = .068, ATS = 5.73 | p = .543, ATS = .75 | p = .788, ATS = .37 | p = .788, ATS = .34 |
| **Distance** | p = .383, ATS = 1.47 | p = .869, ATS = .06 | p = .383, ATS = 1.39 | p = .327, ATS = 2.06 | p = .229, ATS = 2.31 | p = .869, ATS = .16 |

| *post hoc ANOVAs MovC* | Session | Condition | Block step | Session by condition | Session by block step | Condition by block step |
|---|---|---|---|---|---|---|
| **Synchrony** | ***** p < .001, ATS = 18.65** | ***** p < .001, ATS = 34.14** | p = .423, ATS = 1.43 | + p = .053, ATS = 7.39 | p = .515, ATS = 1.03 | p = .920, ATS = .26 |
| **Strength of relation** | ***** p < .001, ATS = 20.25** | ***** p < .001, ATS = 19.91** | p = .498, ATS = 1.22 | p = .292, ATS = 2.79 | p = .423, ATS = 1.37 | p = .971, ATS = .11 |
| **Stability of relation** | p = .125, ATS = 4.87 | p = .423, ATS = 1.44 | p = .579, ATS = .92 | p = .497, ATS = 1.05 | p = .184, ATS = 2.97 | p = .423, ATS = 1.45 |
| **Time lag** | + p = .084, ATS = 5.35 | p = .184, ATS = 3.56 | p = .372, ATS = 1.69 | p = .884, ATS = .15 | p = .995, ATS = .07 | p = .423, ATS = 1.63 |
| **Switching** | p = .278, ATS = 2.55 | p = .883, ATS = .14 | p = .928, ATS = .20 | p = .527, ATS = 1.02 | p = .813, ATS = .42 | p = .928, ATS = .20 |
| **Mutual Information** | p = .141, ATS = 4.14 | ***** p < .001, ATS = 40.55** | ***** p < .001, ATS = 13.03** | *** p = .046, ATS = 7.77** | p = .310, ATS = 2 | *** p = .020, ATS = 9.91** |
| **Phase slope index** | p = .141, ATS = 4.36 | p = .196, ATS = 3.5 | p = .813, ATS = .45 | p = .920, ATS = .07 | p = .920, ATS = .28 | p = .423, ATS = 1.47 |

| *MANOVAs and post hoc ANOVAs* | Trial step |
|---|---|
| **Gaming behaviour** | ***** p < .001, MATS = 203.13** |
| **Basic movement** | ***** p < .001, MATS = 3.9** |
| **Movement coordination** | ***** p < .001, MATS = 16.95** |
| **Targets** | ***** p < .001, ATS = 19.73** |
| **Obstacle time** | ***** p < .001, ATS = 155** |
| **Path length** | ***** p < .001, ATS = 102.81** |
| **Number of moves** | **** p = .005, ATS = 14.08** |
| **Distance** | ***** p < .001, ATS = 21.79** |
| **Synchrony** | **** p = .006, ATS = 8.51** |
| **Strength of relation** | ***** p < .001, ATS = 13.26** |
| **Stability of relation** | p = .997, ATS = .04 |
| **Time lag** | **** p = .006, ATS = 8.48** |
| **Switching** | p = .141, ATS = 3.62 |

**Table A.I.2** Separate MANOVA and post hoc ANOVAs for the effect of trial step. p-values are FDR corrected at the MANOVA level (together with the MANOVAs of session, condition and block step), as well as within each family at the ANOVA level (together with the ANOVAs of session, condition and block step). Significance levels are additionally indicated by *** (p < .001), ** (p < .01).

**Table A.I.3** Post hoc paired comparisons for significant and trending two-way interaction effects with block step. p-values are FDR corrected within each family (together with the ANOVAs for the effects of session, condition and block step, as well as post-hoc paired comparisons for individual block and trial steps). Significance levels are additionally indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10). The three-way interaction effect is not included in this table: all p > .18 and all MATS/ATS < 1.8.

| *post hoc paired comparisons ANOVA (interaction effects)* | Session by block step (1-2) | Session by block step (2-3) | Session by block step (1-3) | Condition by block step (1-2) | Condition by block step (2-3) | Condition by block step (1-3) |
|---|---|---|---|---|---|---|
| **Predictability** | *** p = .024, ATS = 10.93** | + p = .100, ATS = 4.89 | p = .545, ATS = .62 | + p = .072, ATS = 6.48 | p = .819, ATS = .12 | + p = .056, ATS = 7.65 |
| **Complexity** | x | x | x | p = .615, ATS = .39 | *** p = .044, ATS = 6.17** | *** p = .047, ATS = 5.30** |
| **Mutual Information** | x | x | x | p = .288, ATS = 2.65 | *** p = .021, ATS = 10.8** | *** p = .037, ATS = 9.83** |

| | |
|---|---|
| x | Interaction effect not significant / no trend. |

**Table A.I.4** Post hoc ANOVAs - paired comparisons of individual block and trial steps for measures that show significant main effects of block or trial step, respectively. p-values are FDR corrected within each family of observation - together with the ANOVAs for the effects of session, condition and block step, as well as post-hoc paired comparisons for significant interaction effects. Significance levels are additionally indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10).

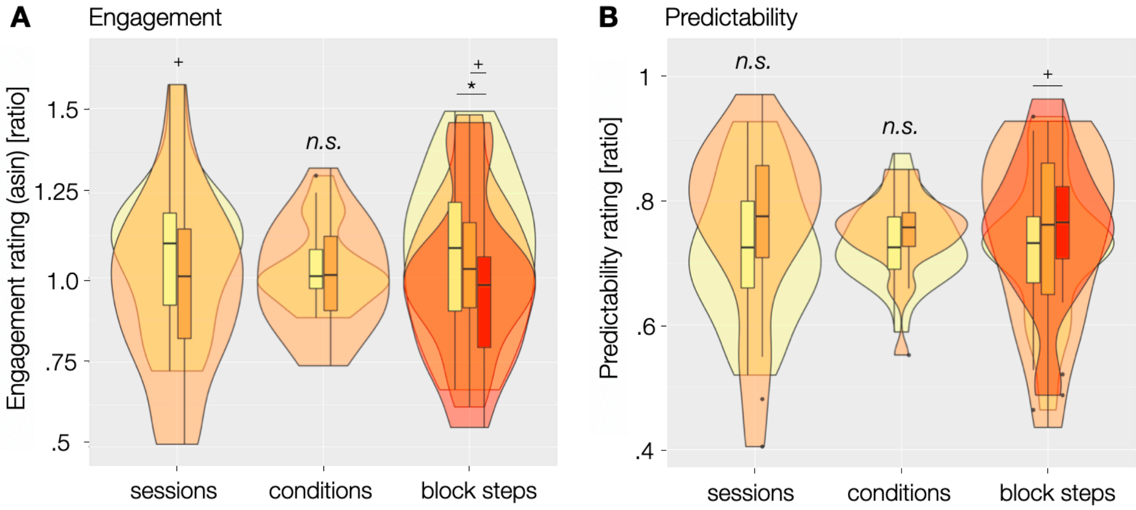
| *Post hoc paired comparison* ***ANOVAs*** | **Block step 1 vs 2** | **Block step 2 vs 3** | **Block step 1 vs 3** | **Trial step 1 vs 2** | **Trial step 2 vs 3** | **Trial step 1 vs 3** |
|---|---|---|---|---|---|---|
| **Engagement** | p = .224, ATS = 2.64 | + p = .053, ATS = 6.37 | *** p = .017, ATS = 16.54** | x | x | x |
| **Agreement** | p = .975, ATS = 0 | *** p = .045, ATS = 8.37** | + p = .053, ATS = 6.67 | x | x | x |
| **Predictability** | p = .306, ATS = 1.77 | p = .458, ATS = .94 | + p = .084, ATS = 5.71 | x | x | x |
| **Targets** | p = .478, ATS = .91 | *** p = .030, ATS = 7.87** | ***** p < .001, ATS = 15.75** | ***** p < .001, ATS = 33.66** | ***** p < .001, ATS = 44.52** | *** p = .012, ATS = 8.83** |
| **Obstacle time** | p = .776, ATS = .14 | **** p = .005, ATS = 11.17** | ***** p < .001, ATS = 23.39** | + p = .098, ATS = 3.81 | ***** p < .001, ATS = 160.4** | ***** p < .001, ATS = 712.9** |
| **Path length** | p = .570, ATS = .50 | ***** p < .001, ATS = 21.21** | ***** p < .001, ATS = 22.63** | ***** p < .001, ATS = 123.3** | **** p = .006, ATS = 10.75** | ***** p < .001, ATS = 111.1** |
| **Complexity** | p = .312, ATS = 1.68 | + p = .083, ATS = 4.77 | p = .571, ATS = .49 | x | x | x |
| **Number of moves** | p = .318, ATS = 2.03 | **** p = .005, ATS = 14.53** | *** p = .042, ATS = 6.98** | ***** p < .001, ATS = 30.36** | + p = .090, ATS = 5.81 | *** p = .042, ATS = 7.69** |
| **Distance** | x | x | x | ***** p < .001, ATS = 36.33** | p = .383, ATS = 1.44 | ***** p < .001, ATS = 20.69** |
| **Synchrony** | x | x | x | p = .230, ATS = 2.92 | **** p = .006, ATS = 10.96** | **** p = .006, ATS = 11.76** |
| **Strength of relation** | x | x | x | p = .125, ATS = 4.78 | ***** p < .001, ATS = 14.85** | ***** p < .001, ATS = 18.94** |
| **Time lag** | x | x | x | *** p = .039, ATS = 6.95** | p = .299, ATS = 2.25 | ***** p < .001, ATS = 13.37** |
| **Mutual Information** | p = .813, ATS = .24 | ***** p < .001, ATS = 16.25** | ***** p < .001, ATS = 15.27** | x | x | x |

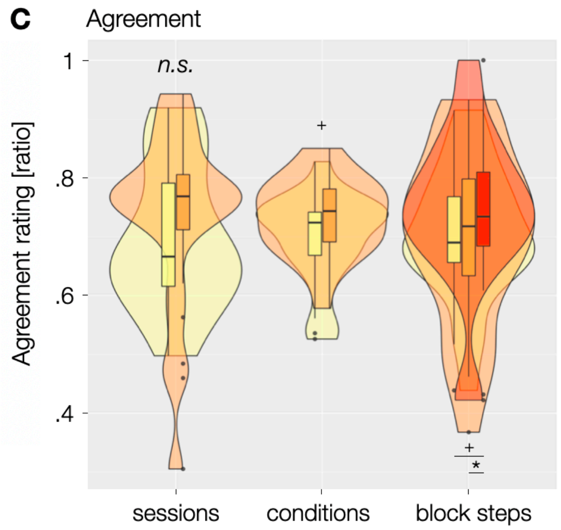
| | |
|---|---|
| x | Data not available at the level of the trial step. |
| x | Main effect (of block or trial step) not significant / no trend. |

## Supplementary Materials I.D

## Illustration of effects from the ANOVA over sessions, conditions and block steps

*Experience*



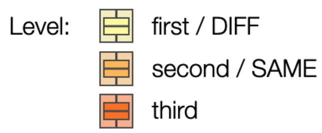
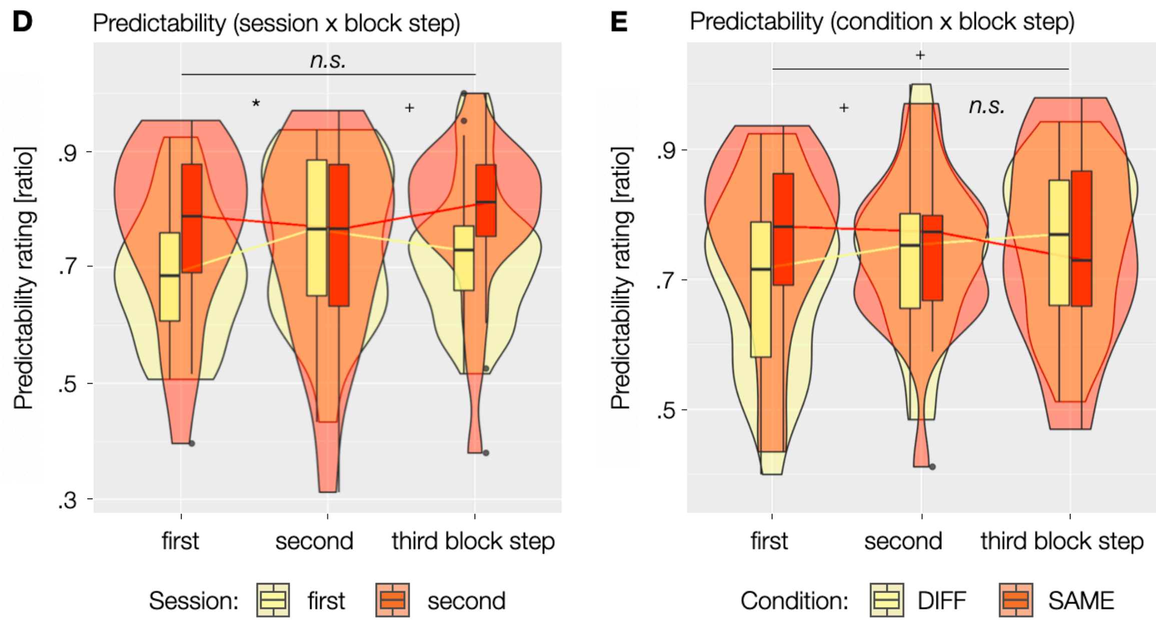
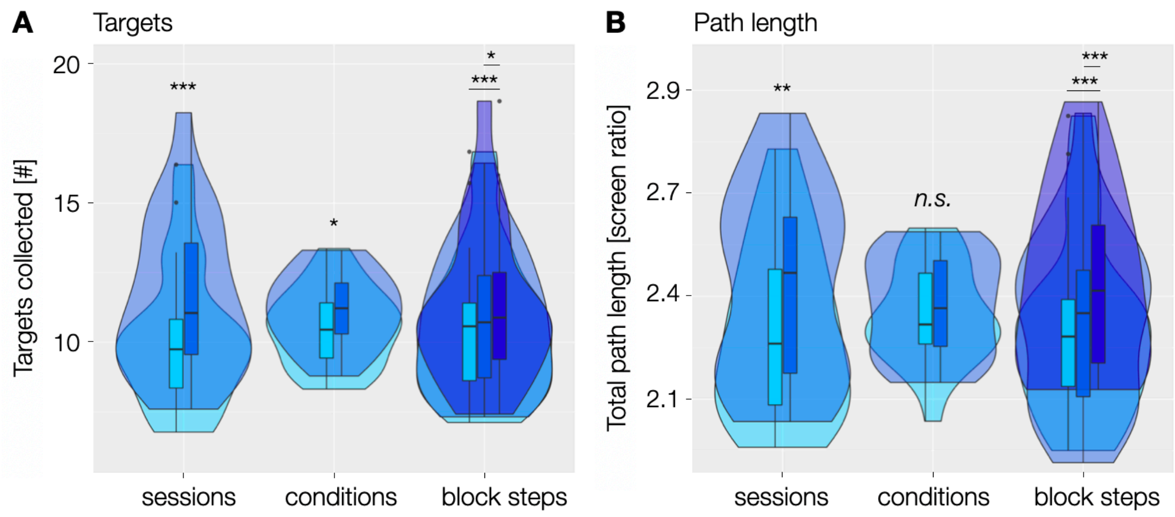
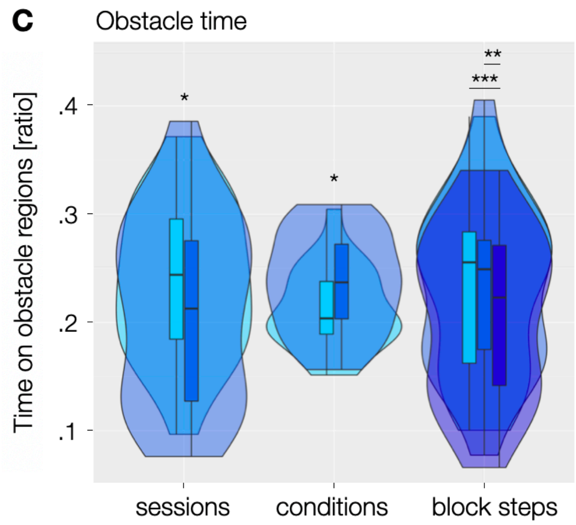




**Figure A.I.2** Main and Interaction effects from the post hoc individual measure ANOVAs for the family of experience ratings. Post hoc statistics were calculated for trends and significant effects (p < .10). All p-values are within-family FDR corrected and indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10) and *n.s.* (p >= .10).





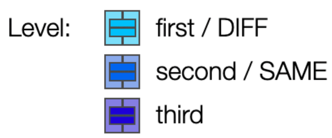
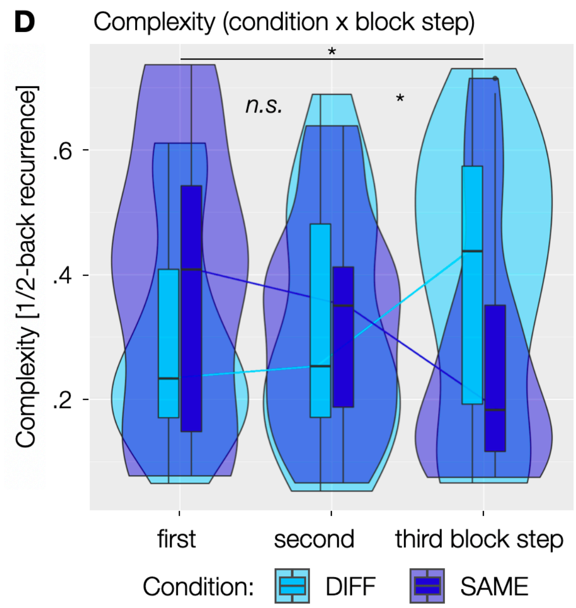
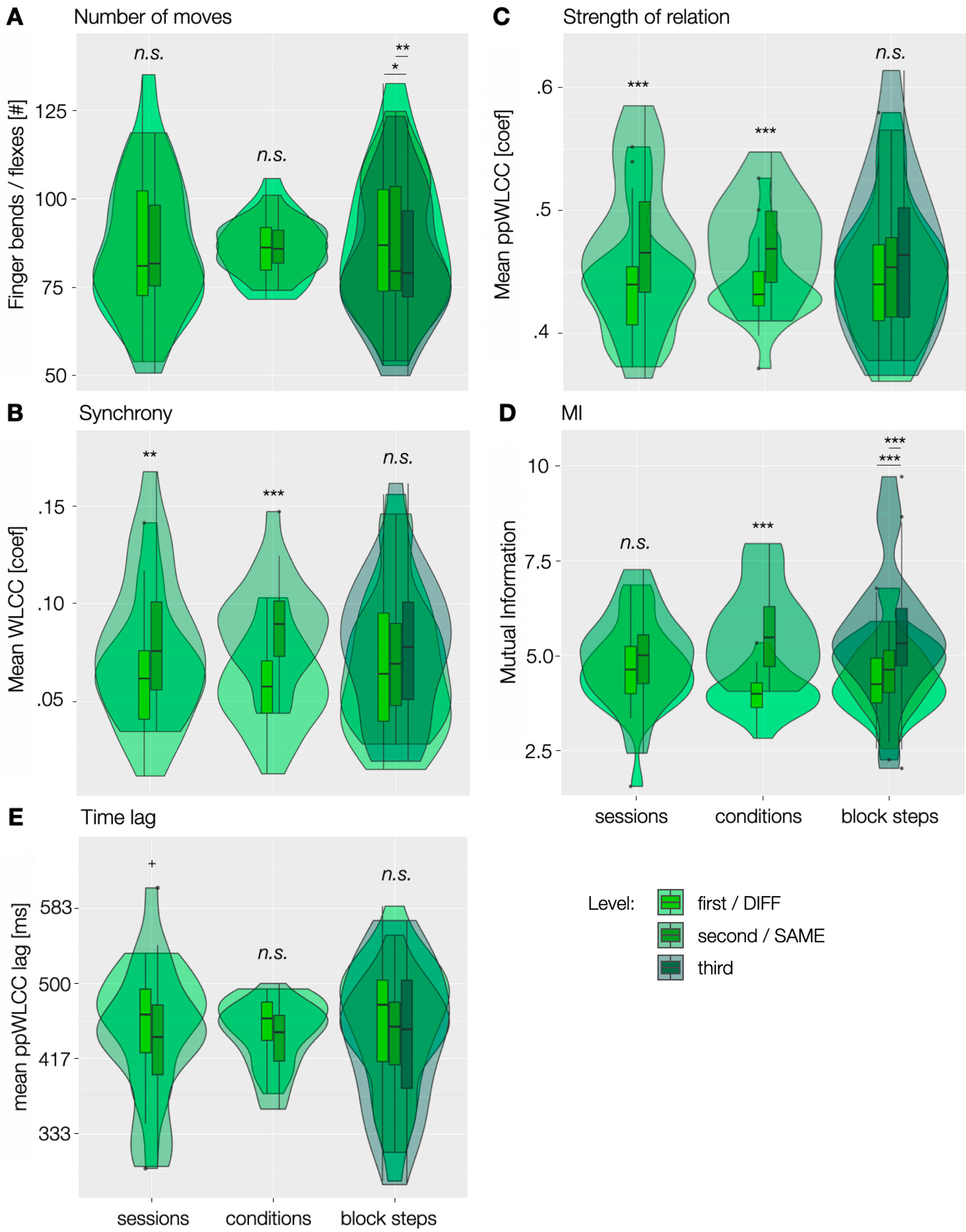




**Figure A.I.3** Main and Interaction effects from the post hoc ANOVAs - the family of finger movement. Within-family FDR corrected p-values are indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10) and *n.s.* (p >= .10).




A
Number of moves
Finger bends / flexes [#]
50
75
100
125
n.s.
n.s.
**
*
C
Strength of relation
Mean ppWLCC [coef]
.4
.5
.6
***
***
n.s.
B
Synchrony
Mean WLCC [coef]
.05
.10
.15
**
***
n.s.
D
MI
Mutual Information
2.5
5.0
7.5
10
n.s.
***
***
***
sessions
conditions
block steps
E
Time lag
mean ppWLCC lag [ms]
333
417
500
583
+
n.s.
n.s.
sessions
conditions
block steps
Level:
first / DIFF
second / SAME
third

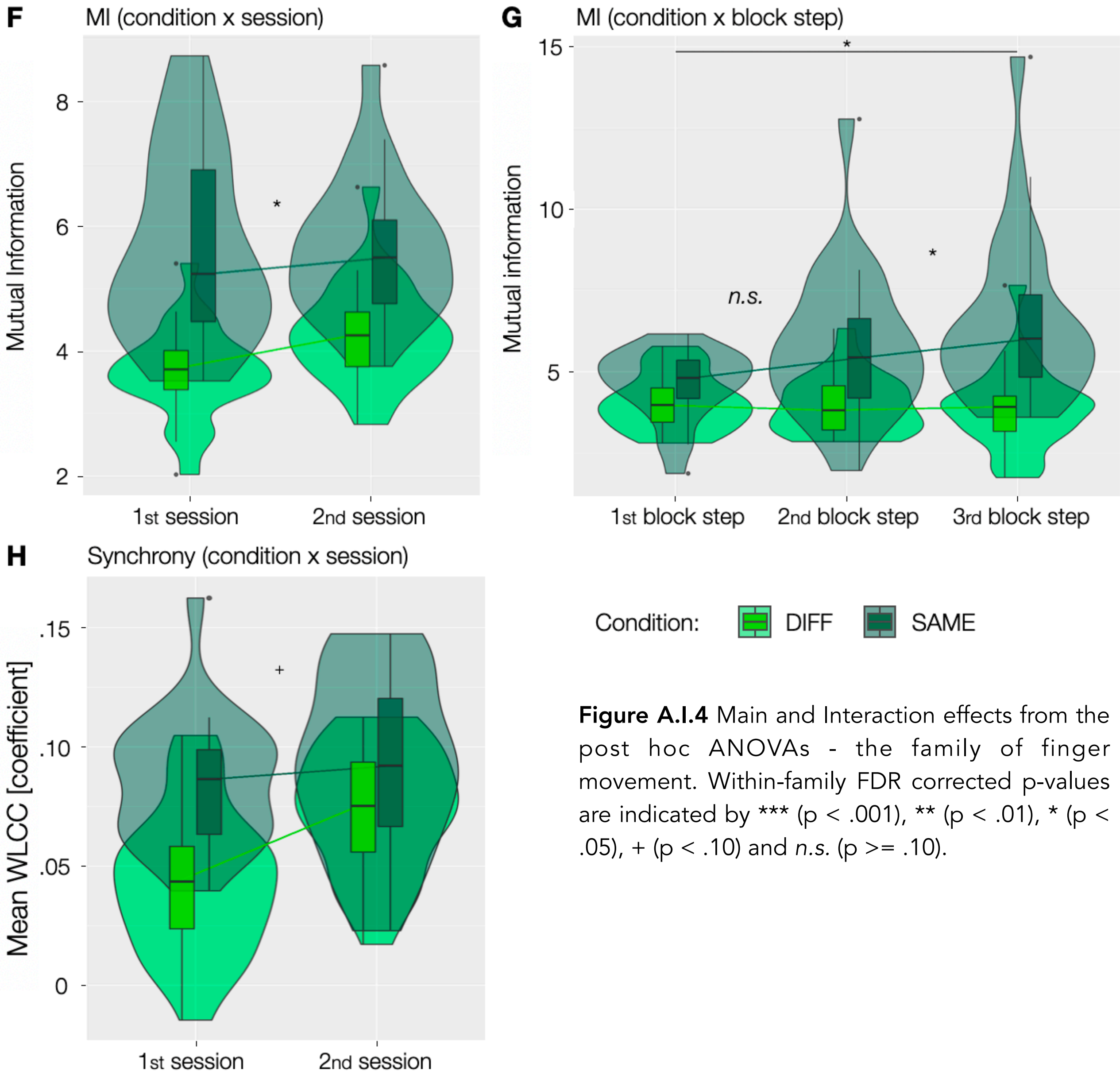



**Figure A.I.4** Main and Interaction effects from the post hoc ANOVAs - the family of finger movement. Within-family FDR corrected p-values are indicated by *** ($p < .001$), ** ($p < .01$), * ($p < .05$), + ($p < .10$) and *n.s.* ($p >= .10$).

## Supplementary Materials I.E

## Illustrations of the main effect of trial step (ANOVA)

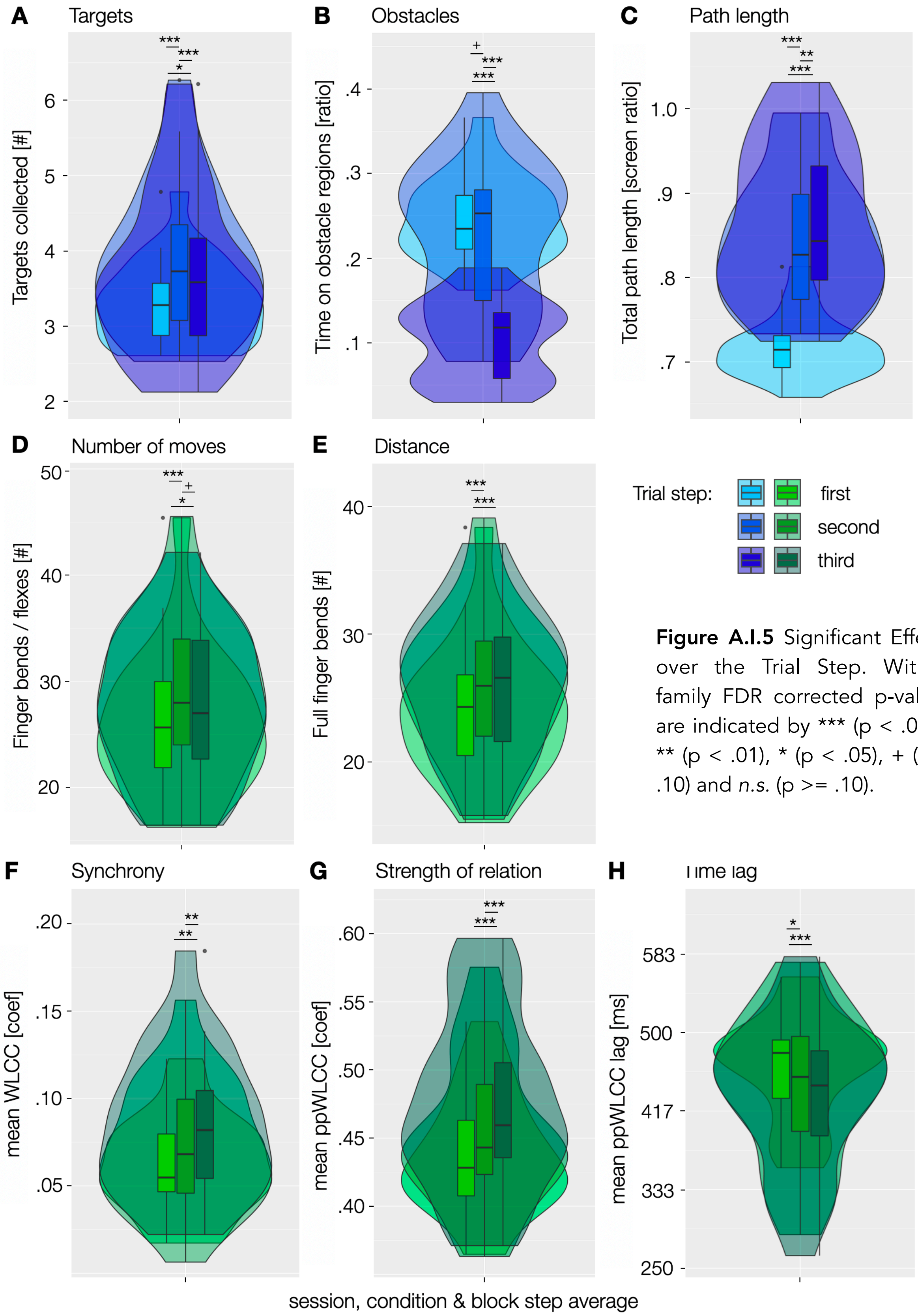



**Figure A.I.5** Significant Effects over the Trial Step. Within-family FDR corrected p-values are indicated by *** ($p < .001$), ** ($p < .01$), * ($p < .05$), + ($p < .10$) and *n.s.* ($p >= .10$).

**Supplementary Materials I.F**

**Participant Interview**

*Q1 - When you think back to playing the BallGame, what comes to mind?*
*Q2 - How would you tell a friend about this experience?*
*Q3 - During the BallGame, what was most present for you, what did you focus on?*
*Q4 - Is there anything that was (a) easy, (b) exhausting or (c) fun?*
*Q5 - What would you compare your experience of the BallGame to? (games, everyday life)*
*Q6 - Was your partner present to you? If so, when and how?*
*Q7 - What was it like to play alone again in the end, after the joint play period?*
*Q8 - Did you play according to one or several specific strategies?*
*Q9 - Is there anything you would like to add?*

*Scaled questions:*

*Q10 - How easy or difficult was it to control the movement of the ball through your finger movements?*
- *very easy 0 to 10 very difficult*
- *individual vs joint play*
- *early vs late in the game*

*Q11 - Did the controller irritate you?*
- *not at all 0 to 10 very much so*
- *early vs late in the game*

*Q12 - Was it easy for you to learn and orient within the BallGame?*
- *very easy 0 to 10 very difficult*
- *individual vs joint play*

*Q13 - Did you experience the BallGame more as a computer task, or more as a social interaction?*
- *PC 0 to 10 social*

*Additional questions about social experience:*

*Q14 - What characterises social interactions that you (do not) enjoy?*
*Q15 - (When) Do you enjoy leading, or following another person's leadership?*

**Supplementary Materials I.G**

**Thematic content analysis** - example quotes from each theme and code identified in a thematic content analysis of post-game participant interviews.

| | *Code* | *Example quotes* |
|---|---|---|
| Game Environment | *ball, steering* | "*My focus? On the ball*", (Pa5P2 [Pair 5, Player 2], Pa13P2, Pa14P2, ..); "*moving (the ball) faster..*", Pa13P1, Pa22P1; "*trying to steer the ball together..*", Pa15P1; "*different from my partner - I wanted to steer with perfect precision, also collect coins, but mostly steer well*", Pa16P1; "*it was fun when it went well - the coordination, and the steering*", Pa20P2 |
| | *coins, targets* | *"when I think back to the game, the coins come to mind.. - getting as many as possible!"*, (Pa2P1, Pa4P1, Pa4P2, Pa7P1, Pa8P1, Pa9P1, Pa13P2, ..); *"to reach the coins - be disappointed when they re-appear.."* (Pa3P2); *"there was R2D2 on the coins.. :)"*, Pa3P1; *"frustrating to be stopped right before the coins, even more when playing together.."*, Pa5P1 |
| | *invisible obstacles* | *"especially when together - where are the invisible obstacles?"*, (Pa4P1, Pa7P1, Pa7P2, Pa8P2, Pa21P1, ..); *"it was complicated - is there an invisible obstacle? the not-knowing.."*, (Pa5P1, Pa6P1, Pa19P2); *"then I realised - a free path is not actually free, there are always invisible obstacles!"*, Pa10P2; *"to remember where they are.."*, (Pa15P2, Pa17P2, Pa18P2) |
| | *obstacles* | *"the red bars come to mind.."* (Pa3P2, Pa6P1, Pa11P2, Pa16P2, ..); "*..without running into / touching the obstacles!*" (Pa2P1, Pa9P2, Pa13P1, Pa16P1, ..); "*the obstacles.. being slowed down*", (Pa11P1, ..); "*better stay close to the obstacles I can see, that is smart - these I can at least see!*", (Pa3P1, Pa11P2, Pa17P2, Pa19P1) |
| | *path* | "*find the shortest / easiest path!*", (Pa6P1, Pa6P2, Pa8P2, Pa11P2, ..); "*better go in curves, direct is usually blocked*", Pa2P1; "*before each trial, we had this moment - to think about which path to take*", (Pa2P2, Pa6P1); "*go fast from A to B*", Pa7P1; "*to have a plan..*", Pa10P2; "*that moment of - ah, here is a path!*", Pa19P1; |
| Individual Play | *active, focused* | "alone - really just focus on steering well, staying on track, getting as many coins as possible", (Pa4P1, Pa21P2, Pa19P1); "*when I played alone, I felt more active*", Pa20P1; "*I really know how this works now, the steering, and I can choose*", (Pa12P2, Pa20P2, Pa20P1); "*I explored more when I played alone*", Pa1P1 |
| | *boring, missed partner* | "*it was a bit boring in the end - I missed my partner, when I didn't want to move, she helped me*", Pa1P2; "the steering was ok but it was a bit boring.. (together it was more fun!)", (Pa4P2, Pa6P2, Pa12P2, Pa15P1, Pa17P1, ..); *"just going through the motions (back and forth), working it off"*, (Pa8P1, Pa9P2); *"in the beginning of the session, it was still fun to play alone (I didn't yet know how to play) - in the end not anymore, it was boring (because I no longer had to coordinate with my partner..)"*, (Pa10P1, Pa19P2) |
| | *poor concentration* | "exhausting? The duration - especially playing alone in the end!", (Pa4P1, Pa14P2, Pa23P1); "*even though I had mastered the finger-thing, it was more exhausting in the end, I simply couldn't focus, tired*", (Pa7P1, Pa21P2); "*concentration was much worse*", (Pa17P2, Pa22P2) |
| | *readjustment* | "*it was a readjustment..*", Pa17P2; "*alone I couldn't handle being stuck on an obstacle - together it was somehow much easier*", Pa2P2; "*like, steering a really nice smooth curve - that went better together, being 'fluent'!*", Pa12P1; "*alone it was more difficult to steer*", (Pa3P2, Pa5P1); "*the steering was unusual - my partner must have kept me on track before :)*", Pa6P1 |
| | *relaxed, better* | "*easy? to know where the invisible obstacles are, when playing alone!*", (Pa3P1,); "*was better to play alone because you could control the ball (find and stick to the shortest path)*", (Pa3P1, Pa14P1); "*easy? playing alone (more relaxed)*", (Pa1P1, Pa4P1, Pa5P2, Pa9P1, Pa14P1, Pa15P2); "*more fun, playing alone!*", Pa7P2; "*alone it was even better because it worked even better*", Pa9P2; "less obstacle collisions, fewer irritations", (Pa11P1, Pa22P1, Pa23P1, Pa23P2) |

| | Code | Example quotes |
|---|---|---|
| | *similar, evens out* | “*back and forth, if it doesn’t work, swap route - very similar alone and together!*”, Pa2P2; “*not such a big difference, similar performance*”, Pa11P2; “*sort of evens out - easier because of the ball control, more difficult because of 3 completely invisible obstacles - you could somehow feel where the invisibles (visible to my partner) were, when playing together..*”, Pa18P2 |
| | *ball slower* | “*alone slower than together!*”, (Pa17P1, Pa17P2, Pa2P1); “*together it was fun - when it worked, you were even faster than when alone!*”, Pa6P2; “*I felt like I was slower, alone..*”, Pa12P1 |
| **Negative Mood** | *annoyed* | “*these annoying invisible obstacles..*”, Pa2P1; “*somehow it was a bit stressful (not knowing what the other wants now*”, (Pa4P1, Pa15P2); “*argh, when the ball goes into another direction, not the one I wanted..^^*”, Pa6P2; “*come on…!*”, Pa11P1; “*when the other sees the obstacle, but, cannot simply decide where we go - - when it took longer than necessary to solve a block/obstacle*”, (Pa12P1, Pa8P2); |
| | *confused, unpredictable* | “*like packman with noise / a disturbing factor..*”, Pa3P1; “*steering was somehow strange. as if it didn’t always react the same way*”, Pa10P2; “*exhausting. I felt like I couldn’t do much - I tried to listen and respond to her strategy - sometimes it worked, sometimes it didn’t*”, Pa20P1 |
| | *exhausted, repetition* | “*the problem was monotony - the coins appeared at the same spots, that could be exploited*”, Pa18P2; “*focus, coordination, staying engaged - phuh*”, (Pa7P2, Pa10P2); “*exhausting with the fingers - I really had to focus hard..*”, Pa20P2; “*exhausting? The repetition*”, Pa1P2; “*the control tasks were really exhausting. just staring at the screen..*”, (Pa2P2, Pa3P1, Pa6P2, Pa7P1, Pa10P1, Pa22P1) |
| | *slow, blocked* | “*slowing down, feeling blocked (through partner / obstacle).. not moving - argh*”, (Pa4P1, Pa9P1, Pa16P2, Pa19P2); “*when you tried, but, you were stopped*”, Pa20P1; “*obstacles, being blocked, slowed down, not being able to have my way - that was frustrating*”, (Pa11P1) |
| **Positive Mood** | *challenging* | “*I was motivated to collect the coins - you really enter the game!*”, Pa7P1; “being able to steer through small paths between obstacles - nice, he thinks exactly like me!”, Pa17P1; “*not easy but you can figure it out! many small moments of success - difficult, but, we made it: I am steering by myself! that’s how I felt*”, Pa17P1; “*I enjoyed the challenge of it!*”, Pa3P2; “*the moments where we were looking out for each other, working towards a shared solution together - that was fun*”, Pa12P2 |
| | *easy* | “*the back and forth strategy - (I was relieved to see that) we easily settled on that! :)*”, (Pa9P1, Pa19P2); “*moving the ball, easy, like an extension of the body*”, Pa3P2; “*the steering was easier than I thought!*”, (Pa1P1, Pa7P2, Pa8P1, Pa9P1, Pa19P2); “*when you had a feeling for what the other wants, then it was easy / good..*”, Pa16P2; |
| | *individual play* | “*fun? playing alone. when together, there were irritations*”, Pa11P1; “*alone much more fun, invisible obstacles easy.. yes..*”, Pa15P2; “*playing alone I had most fun*”, Pa23P2 |
| | *joint play* | “*fun? playing together! not only coins, also coordinating! (learning about the other / to coordinate)*”, (Pa4P2, Pa5P1, Pa5P2, Pa7P1, Pa8P1, Pa9P1, Pa11P2, ..); “*..especially when we wanted the same thing (were in a flow)..*”, (Pa6P1, Pa11P1, Pa12P1); “*when it worked well together - had to suppress laughter!*”, Pa22P1; “*really surprising, how well it went, together!*”, Pa1P1; “*during joint play, I was somehow driven!*”, Pa3P1; “*It worked so well, didn’t even feel like playing together!*”, (Pa17P1, Pa23P2); “*especially the second half - we went back and forth, it made ‘klick’ - we both gave it our best!*”, Pa14P2 |
| | *overall* | “*was fun after all! (I didn’t check the time)*”, (Pa1P1, Pa18P1, Pa3P1, Pa18P2); “*really cool experiment! (no ‘experiment experience’ for me! [you can move your eyes..] more just) a game, two people, two rooms, steer ball together - collect coins*”, (Pa2P2, Pa17P1, Pa19P2); “*I was deeply engaged*”, Pa21P2; |

| | Code | Example quotes |
|---|---|---|
| | *rhythm, flow* | "*being fluent*", Pa12P1; "*one wavelength*", Pa10P2; "*together and unanimous - mm!*", Pa19P2; "*over time, more control, new paths, more fluent*", Pa11P1; *after a while, having found a rhythm, coordinating just through finger-movements, cool*", Pa8P2 |
| | *success* | "*Success, cooperation*", Pa14P1; "*reaching targets*", (Pa16P1, Pa16P2, Pa17P1, Pa21P1); "*when we managed to quickly identify our path..*", (Pa1P2, Pa6P1) |
| **Social Presence** | *attune (self & other)* | "*I focused, consciously, especially in the beginning of the trial: where does my partner want to go?*", Pa15P2; "*more just coordinating, settling, coming to agreement..*", (Pa4P1, Pa17P1); "*working as a team, trying to understand the intentions of the other*", (Pa13P2, Pa22P2); "*coordination, thinking of one's partner, being considerate - brings us faster to our goal*", Pa18P1; "*when playing together - waiting, what does my partner want - is what I want against this? once this is settled, it is like playing alone*", Pa19P1; "*motor coordination and expectation - learn steer the ball, figure out what the other plans to do, adapt to that*", Pa23P1 |
| | *whole time* | "*somehow the whole time - when it didn't work, or, when it went really well - increasingly, over the course of the game*", Pa22P1; "*I rather had a 'we-feeling', than thinking of her explicitly..*", Pa2P2; "*throughout the game - where does he go, what does he want, I want him to go here now, or, argh, he wants something else.. everything really..*", Pa15P1 |
| | *flow* | "*I had a good feeling for my partner - she didn't block me and we could always find a path together*", Pa1P2; "*When it was clear what we wanted to do, then my partner was especially present*", (Pa17P1, Pa23P1) |
| | *indirect* | "steering, *collecting coins with someone you can't see, no verbal back and forth..*", (Pa6P2, Pa15P2); "*not knowing when you see different things..*", Pa15P1; "*not knowing what the other is doing..*", Pa17P2; "you know you make an effort, try to communicate, signal..", Pa21P2 |
| | *unclear (us or obstacle)* | "*when it didn't go well - why? What does she want? Does she have an obstacle? Why can't we move on*", (Pa5P2); "*in part funny - you don't know if it's an invisible obstacle or your partner who doesn't collaborate*", Pa12P2; "*sometimes difficult to know what the other wants - maybe there is an invisible obstacle that my partner can see?*", Pa9P2; |
| | *blocked* | "*thinking of my partner? When blocked..*", (Pa2P1, Pa3P2, Pa4P1, Pa4P2, Pa5P1,..); |
| **Strategy** | *listen, where to go* | "when playing together, *first wait, then support her*", Pa1P1; "n*otice when partner wants to avoid an obstacle - respond to that, because I cannot see it*", Pa3P1; "*waiting, to know where the partner wants to go*", Pa9P1; "*does she want to go somewhere else? then go along*", Pa11P1; "*invisible obstacles - know where they are, so I can let my partner lead around them. Listen*", Pa14P1; "*how he steered - if against me. notice that*", Pa18P2; "*together it is even more complex - trying to perceive the other, their intentions - especially in the beginning of a trial*", Pa21P2; "when together, *figure out what the other wants/plans*", Pa23P1 |
| | *back & forth* | "*go back and forth when we had identified one path*", (Pa1P1, ); "*find simplest path and stay there, between two targets. I already did that when I played alone in the beginning*", Pa1P2; "*the back and forth strategy!*", (Pa2P2, Pa9P1, Pa10P1, Pa10P2, Pa15P1, ..) |
| | *explore* | "*not just back and forth..*", Pa11P1; "*especially when alone - try out more..*", Pa1P1; "*when we played together, I think I was more explorative - simply go for the first coin!*", Pa9P1; "*over time more control, new paths, more fluent*", Pa11P1 |
| | *follow movement, intuitive* | "*steering the ball, like, so that it moves - if it doesn't, better 'let go', go with the other*", Pa21P1; "*there was always somebody who made the first move - follow that! if we wanted the same, back and forth, if we didn't, then swapping between routes..*", Pa2P2; "*sometimes more intuitive - this direction doesn't work? Stay calm, make a few moves, see where he wants to go..*", Pa15P2 |
| | *avoid risks* | "*it's difficult enough to coordinate with the other - better keep it simple!*", Pa11P1; "*find safe and fast path, go, collect - no risks*", Pa12P1; "*only change when it really doesn't work!*", Pa8P1 |

| | Code | Example quotes |
|---|---|---|
| **Technical Comments** | *over time* | “*first figuring out, then fun, then repetitive (lack of focus)*”, (Pa8P2, Pa14P2, Pa21P2, Pa22P1, …); “*at first it was difficult to know what she wants, that got better over time - okay, I have to let go sometimes, check in with where she wants to go*”, Pa9P2; “*the steering got very easy, over time*”, (Pa5P2, Pa10P1) |
| | *setup (ctrl, display, room)* | “*I was thinking about how you realised this - two separate rooms, steering one ball together, all the recordings..*”, Pa14P2; “*I noticed the symbols in the corners - for the eye-tracker?*”, Pa8P2; “*easy to understand - the game mechanism, with the landscapes etc*”, Pa18P2; “*unusual game control!*”, Pa12P1; “*my left finger-controller was a bit loose in the end - I thought - ha, this should go better?*”, Pa2P2; “*just bending and extending the fingers during the baseline tasks - the second time around, I got it.. sorry*”, Pa6P2 |
| | *body in setup* | “*Focus? My finger movements.. to control the ball (together - same as my partner's?) ('Fingerjoystick')*”, (Pa6P2, Pa7P2, Pa9P1, Pa11P2, Pa16P2, ..); “*exhausting - sitting (stiff back)), focusing on the screen, my eyes..*”, (Pa1P1, Pa4P2, Pa5P1, Pa6P1, ..) |

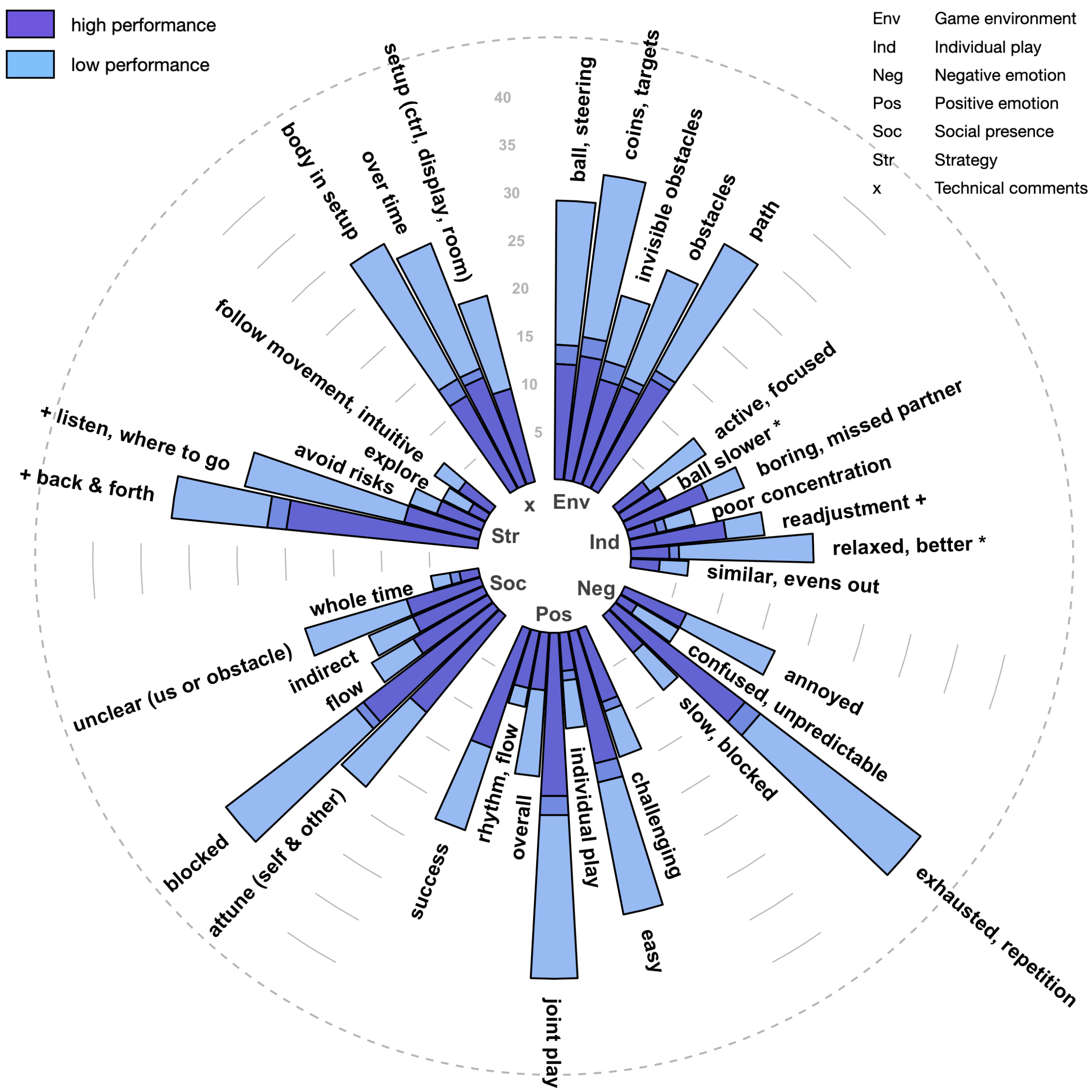



**Figure A.I.6** Thematic Content Analysis of Participant Interviews. Dark versus light blue indicates responses from players in teams with high versus low performance.

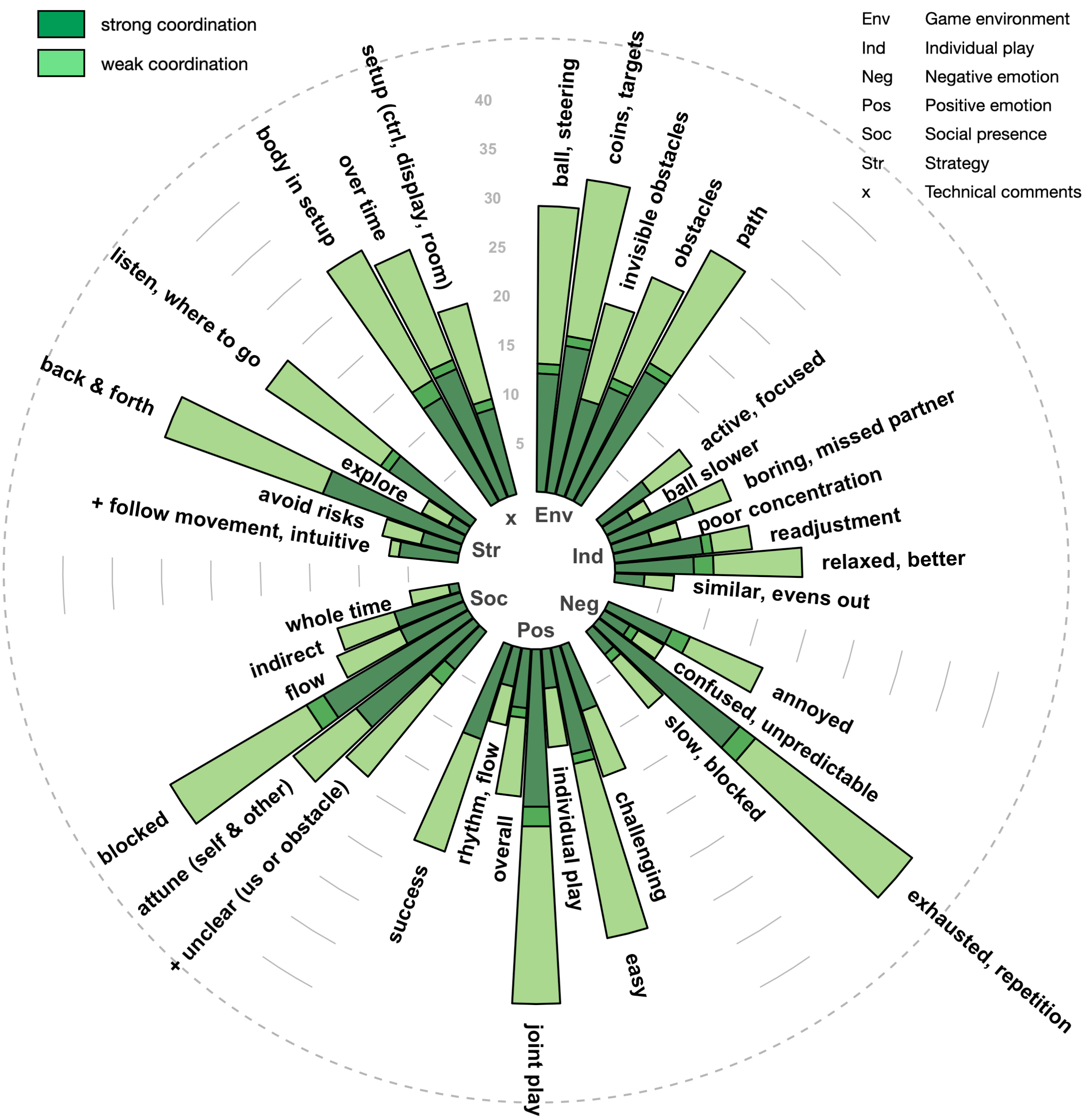



**Figure A.I.7** Thematic Content Analysis of Participant Interviews. Dark versus light green indicates answers from players in teams with strong versus weak movement coordination.

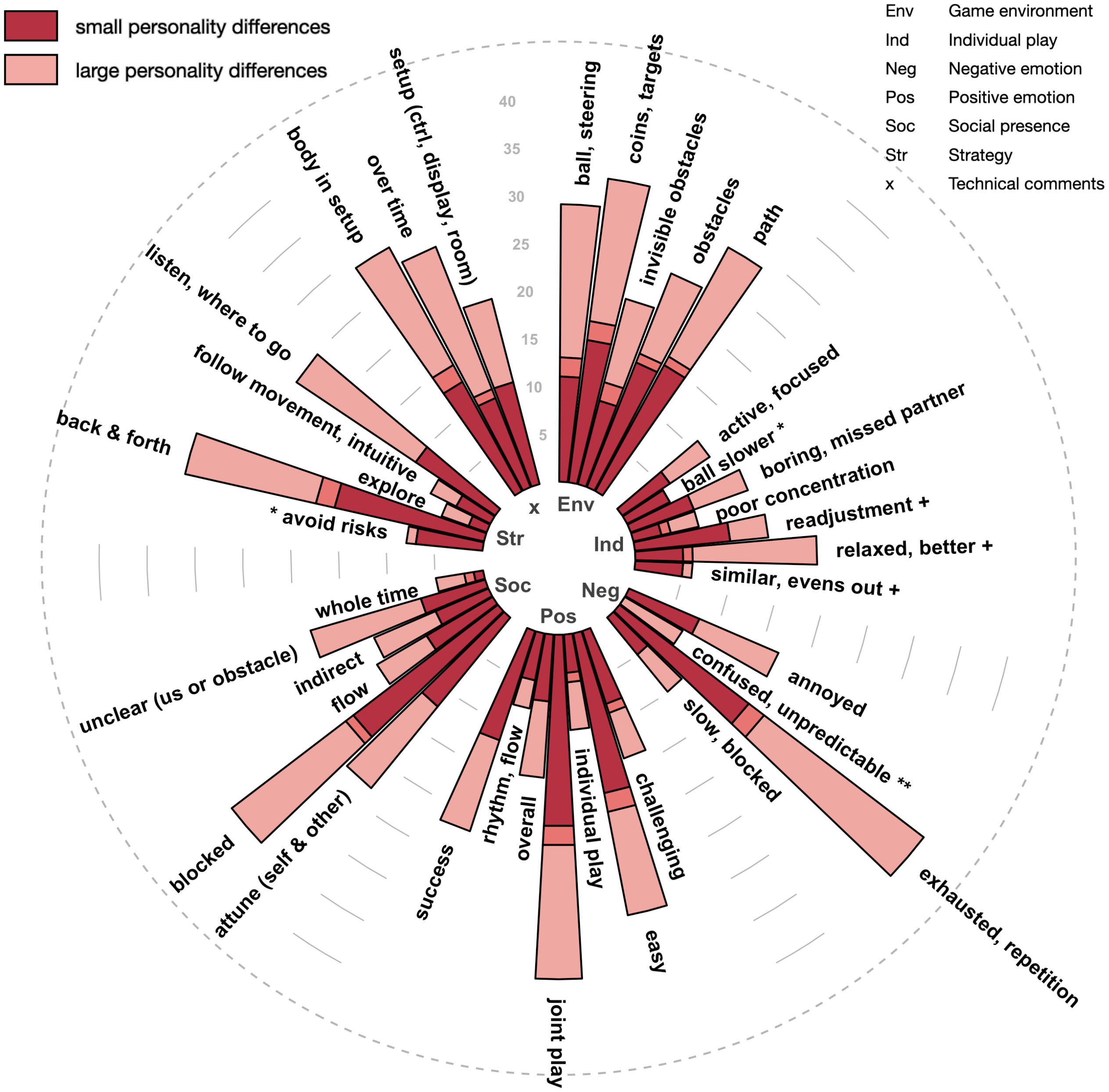



**Figure A.I.8** Thematic Content Analysis of Participant Interviews. Dark versus light red indicates answers from players in teams with small versus large personality differences.

## APPENDIX II

## Supplementary Materials for Chapter 4, the MirrorGame

A. *Individual post-play interview*
B. *Initial and final linear mixed effects models to predict experience*
C. *MANOVA & ANOVAs of movement coordination*
D. *Thematic Content Analysis of the individual interviews - example quotes*

### Supplementary Materials II.A

### Individual post-play interview

This interview was conducted individually with both participants after they had completed the MirrorGame.

*Q1 - Could you give a rough overview of your experience of the game, from beginning to end?*
*Q2 - Which aspects were central to you - how would you tell a friend about this experience?*
*Q3 - How did you answer the question "fun or frustrating"? What made the difference for you?*
*Q4 - When did you decide to mark a 'special moment'? What happened in such a moment?*
*Q5 - Did you use certain strategies to communicate or come to agreement with your partner? Are there typical game situations that you could describe?*
*Q6 - What would you compare your experience of the MirrorGame to?*
*Q6 - How did you experience the different sensory feedback modalities?*
*Q7 - How did you experience the different leadership instructions?*
*Q8 - Is there anything that was exhausting, irritating or surprising?*
*Q9 - Did you find the post-trial rating questions easy to answer / suitable to the task?*
*Q10 - If you could change one thing - what would you change about the MirrorGame?*

*Scaled questions:*

*Q11 - Did you experience the MirrorGame more as a computer game, or a social interaction?*
*• PC 0 to 10 social*

*Q12 - Did you experience your partner as rather intuitive, or logical, or..?*
*• Analytical 0 to 10 intuitive*

*Additional questions about social experience in general:*

*Q14 - What characterises social interactions that you (do not) enjoy?*
*Q15 - (When) Do you enjoy leading, or following another person's leadership?*

*Additional more in-depth exploration of a special moment of experience:*

*Q16 - Could you go back to that moment [fill in] - what exactly happened there for you?*
*Q17 - ..right before, right after - and what else did you experience in that moment?..*

**Supplementary Materials II.B**

**Initial and final Linear Mixed Effects Models to predict experience**

**Tables A.II.1** Statistics of the final and initial mixed effects models to predict experience ratings in the MirrorGame. p-values are FDR corrected for multiple comparisons.

| ***Initial fixed effects*: fluency** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **69.709** | **4.309** | **16.176** | **0.000** |
| **Block of play** | **5.365** | **1.143** | **4.693** | **0.000** |
| Condition: Visual (vs Auditory) | **21.662** | **4.536** | **4.776** | **0.000** |
| Condition: Audiovisual (vs Auditory) | **15.424** | **4.077** | **3.784** | **0.000** |
| Condition: LF (vs JI) | **-5.934** | **3.042** | **-1.950** | **0.052** |
| Position difference | -1.786 | 1.837 | -0.972 | 0.331 |
| **Velocity difference** | **-7.242** | **1.937** | **-3.740** | **0.000** |
| Synchrony (WLCC) | 2.300 | 2.064 | 1.114 | 0.266 |
| Strength of relation (ppWLCC) | 2.071 | 2.292 | 0.903 | 0.367 |
| Stability of relation (ppWLCC) | -0.258 | 1.801 | -0.143 | 0.886 |
| **Time lag (directed) (ppWLCC)** | **2.275** | **1.166** | **1.951** | **0.052** |
| Time lag (absolute) (ppWLCC) | -0.643 | 4.266 | -0.151 | 0.880 |
| Switching | -2.384 | 4.633 | -0.515 | 0.607 |
| Neuroticism differences | 0.184 | 4.074 | 0.045 | 0.965 |
| Extraversion differences | -4.585 | 3.462 | -1.325 | 0.201 |
| **Openness differences** | **8.103** | **3.451** | **2.348** | **0.030** |
| Agreeableness differences | -4.411 | 5.169 | -0.853 | 0.404 |
| Conscientiousness differences | -3.025 | 3.978 | -0.760 | 0.457 |

| ***Final fixed effects*: fluency** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 69.146 | 3.870 | 17.868 | 0.000 |
| Block of play | 4.435 | 1.096 | 4.047 | 0.000 |
| Condition: Visual (vs Auditory) | 18.135 | 4.183 | 4.336 | 0.000 |
| Condition: Audiovisual (vs Auditory) | 12.986 | 3.768 | 3.446 | 0.001 |
| Velocity difference | -6.292 | 1.524 | -4.129 | 0.000 |
| Synchrony | 5.742 | 1.450 | 3.959 | 0.000 |
| Switching | -3.379 | 1.693 | -1.996 | 0.046 |

| ***Final random effects*: fluency** | **variance** | **std. dev** |
|---|---|---|
| Pair intercept | 157.2 (21.48 %) | 12.54 |
| Residual | 574.8 (78.52 %) | 23.98 |
| Number of observations: 511 | Number of pairs: 20 | |

| ***Initial fixed effects*: Fun** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **85.502** | **4.238** | **20.175** | **0.000** |
| Block of play | 0.304 | 0.999 | 0.305 | 0.761 |
| **Condition: Visual (vs Auditory)** | **7.969** | **3.972** | **2.006** | **0.045** |
| **Condition: Audiovisual (vs Auditory)** | **9.455** | **3.566** | **2.651** | **0.008** |
| Condition: LF (vs JI) | -1.433 | 2.660 | -0.539 | 0.590 |
| Position difference | -0.585 | 1.605 | -0.364 | 0.716 |
| Velocity difference | 1.579 | 1.699 | 0.929 | 0.353 |
| **Synchrony (WLCC)** | **3.001** | **1.808** | **1.660** | **0.098** |
| Strength of relation (ppWLCC) | -0.997 | 2.023 | -0.493 | 0.623 |
| Stability of relation (ppWLCC) | 0.434 | 1.575 | 0.276 | 0.783 |
| Time lag (directed) (ppWLCC) | 1.299 | 1.019 | 1.274 | 0.203 |
| Time lag (absolute) (ppWLCC) | 2.133 | 3.731 | 0.572 | 0.568 |
| Switching | -3.759 | 4.049 | -0.928 | 0.354 |
| Neuroticism differences | 3.442 | 4.500 | 0.765 | 0.454 |
| Extraversion differences | -2.098 | 3.818 | -0.549 | 0.589 |
| Openness differences | 4.608 | 3.812 | 1.209 | 0.241 |
| Agreeableness differences | -5.283 | 5.728 | -0.922 | 0.368 |
| Conscientiousness differences | -6.551 | 4.414 | -1.484 | 0.154 |

| ***Final fixed effects*: Fun** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 84.983 | 3.540 | 24.004 | 0.000 |
| Condition: Visual (vs Auditory) | 8.081 | 2.850 | 2.835 | 0.005 |
| Condition: Audiovisual (vs Auditory) | 10.318 | 2.677 | 3.855 | 0.000 |
| Velocity difference | 2.812 | 1.333 | 2.109 | 0.035 |
| Synchrony (WLCC) | 3.306 | 1.256 | 2.633 | 0.009 |

| ***Final random effects*: Fun** | **variance** | **std. dev** |
|---|---|---|
| Pair intercept | 179.8 (29.14 %) | 13.41 |
| Residual | 437.2 (70.86 %) | 20.91 |
| Number of observations: 511 | Number of pairs: 20 | |

| ***Initial fixed effects*: Sense of (short) time** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| **Intercept** | **70.289** | **4.617** | **15.223** | **0.000** |
| **Block of play** | **-2.680** | **0.943** | **-2.841** | **0.005** |
| Condition: Visual (vs Auditory) | -0.407 | 3.758 | -0.108 | 0.914 |
| **Condition: Audiovisual (vs Auditory)** | **5.608** | **3.372** | **1.663** | **0.097** |
| **Condition: LF (vs JI)** | **25.381** | **2.515** | **10.092** | **0.000** |
| Position difference | 0.762 | 1.517 | 0.502 | 0.616 |
| Velocity difference | -1.127 | 1.609 | -0.700 | 0.484 |
| Synchrony (WLCC) | 1.050 | 1.710 | 0.614 | 0.539 |
| Strength of relation (ppWLCC) | -0.413 | 1.924 | -0.215 | 0.830 |
| Stability of relation (ppWLCC) | -0.163 | 1.489 | -0.109 | 0.913 |
| Time lag (directed) (ppWLCC) | 0.009 | 0.963 | 0.010 | 0.992 |
| **Time lag (absolute) (ppWLCC)** | **6.216** | **3.527** | **1.762** | **0.079** |
| Switching | -6.071 | 3.826 | -1.587 | 0.113 |
| Neuroticism differences | 0.856 | 5.356 | 0.160 | 0.875 |
| Extraversion differences | -2.496 | 4.540 | -0.550 | 0.589 |
| Openness differences | 2.780 | 4.538 | 0.613 | 0.547 |
| Agreeableness differences | -8.198 | 6.832 | -1.200 | 0.245 |
| Conscientiousness differences | -6.501 | 5.268 | -1.234 | 0.232 |

| ***Final fixed effects*: Sense of time** | **estimate** | **std. error** | **t value** | **p value** |
|---|---|---|---|---|
| Intercept | 70.918 | 3.995 | 17.753 | 0.000 |
| Block of play | -3.462 | 0.893 | -3.879 | 0.000 |
| Condition: Audiovisual (vs A & V) | 6.697 | 1.848 | 3.624 | 0.000 |
| Condition: LF (vs JI) | 25.484 | 1.894 | 13.458 | 0.000 |

| ***Final random effects*: Sense of time** | **variance** | **std. dev** |
|---|---|---|
| Pair intercept | 261.6 (40.27 %) | 16.17 |
| Residual | 388.0 (59.73 %) | 19.70 |
| Number of observations: 511 | Number of pairs: 20 | |

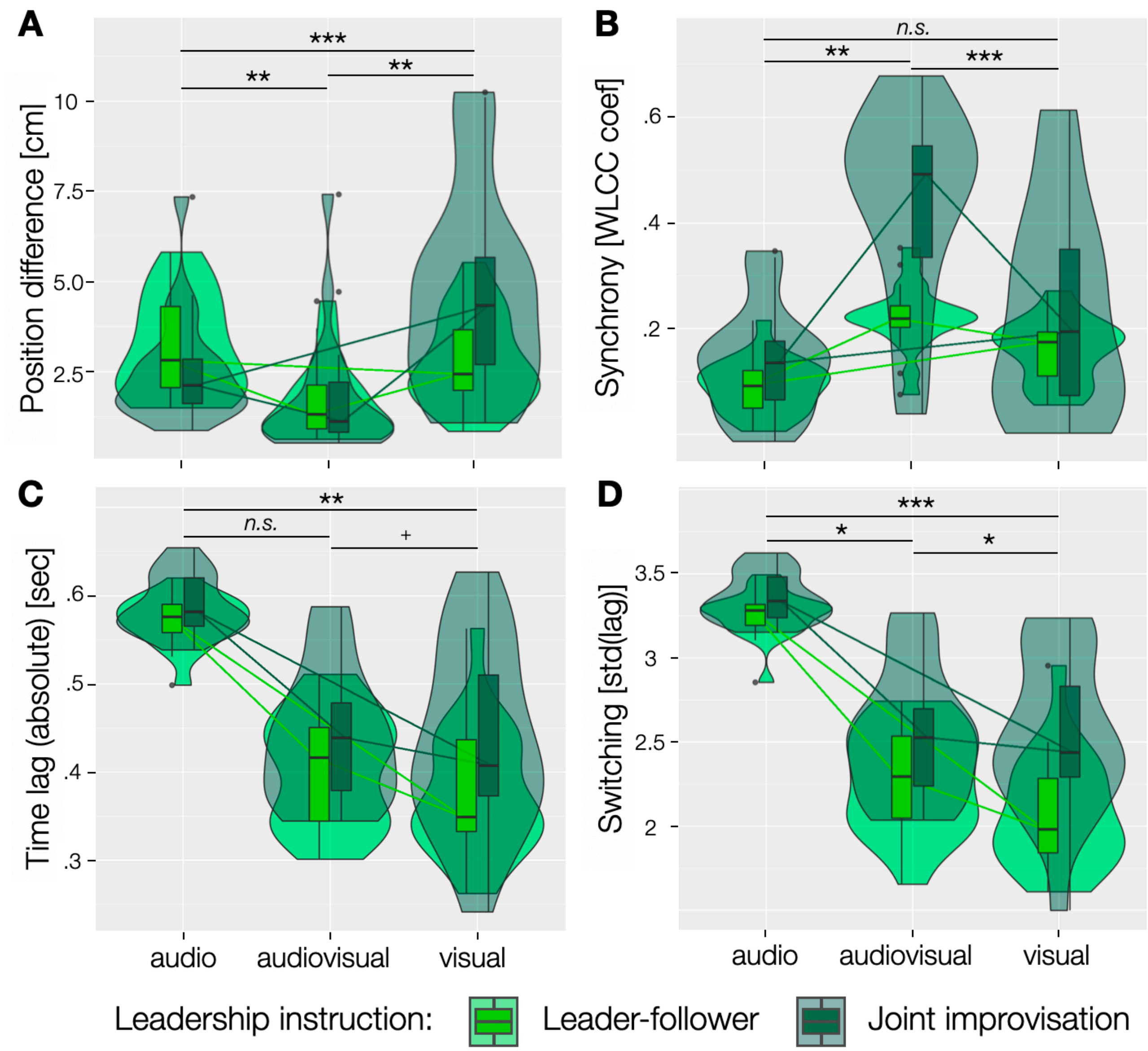
## Supplementary Materials II.C

## MANOVA & ANOVAs of movement coordination

| *Data for LF trials aggregated - except directed time lag!* | Sensory feedback modality | Leadership instruction | Block | Sensory feedback * leadership instr. | Sensory feedback * block |
|---|---|---|---|---|---|
| ***MOVEMENT*** | ***** p < .001**, MATS = 2283.42 | ***** p < .001**, MATS = 156.04 | + p = .061, MATS = 32.7 | ***** p < .001**, MATS = 83.49 | p = .178, MATS = 37.73 |
| **posDif** | **** p = .004**, ATS = 16.56 | p = .166, ATS = 3.35 | p = .425, ATS = 1.38 | **** p = .004,** ATS = 14.69 | p = .463, ATS = 1.14 |
| **velDif** | ***** p < .001,** ATS = 70.60 | *** p = .039,** ATS = 7.29 | p = .166, ATS = 3.16 | + p = .064, ATS = 5.42 | p = .425, ATS = 1.35 |
| **Synchrony** | ***** p < .001,** ATS = 66.02 | ***** p < .001,** ATS = 19.29 | p = .110, ATS = 3.41 | ***** p < .001,** ATS = 14.13 | p = .330, ATS = 1.64 |
| **Strength oR** | ***** p < .001,** ATS = 21.90 | *** p = .014,** ATS = 13.26 | *** p = .039,** ATS = 6.46 | p = .110, ATS = 3.43 | p = .425, ATS = 1.39 |
| **Stability oR** | ***** p < .001,** ATS = 29.47 | *** p = .040,** ATS = 7.36 | *** p = .030,** ATS = 6.75 | p = .255, ATS = 2.15 | p = .425, ATS = 1.31 |
| **Time lag dir** *(directed) - not merged here!* | p = .425, ATS = 1.31 | ***** p < .001,** ATS = 48.45 | p = .620, ATS = .75 | ***** p < .001,** ATS = 25.78 | p = .255, ATS = 1.90 |
| **Time lag abs** *(absolute, un-directed!)* | ***** p < .001,** ATS = 74.36 | ***** p < .001,** ATS = 19.31 | p = .535, ATS = .79 | *** p = .039,** ATS = 4.70 | p = .479, ATS = .98 |
| **Switching** *(merged but based on directed data!)* | ***** p < .001,** ATS = 117.13 | ***** p < .001,** ATS = 37.08 | p = .623, ATS = .54 | ***** p < .001,** ATS = 13.08 | p = .463, ATS = 1.09 |

| *Data for LF trials aggregated - except directed time lag!* | Leadership instr. * block | 3-way interaction |
|---|---|---|
| ***MOVEMENT*** | p = .964, MATS = 2.69 | p = .705, MATS = 13.60 |
| **posDif** | p = .620, ATS = .67 | p = .193, ATS = 2.18 |
| **velDif** | p = .775, ATS = .27 | p = .989, ATS = .04 |
| **Synchrony** | p = .792, ATS = .28 | p = .433, ATS = 1.27 |
| **Strength oR** | p = .750, ATS = .39 | p = .373, ATS = 1.57 |
| **Stability oR** | p = .982, ATS = .05 | p = .495, ATS = 1.07 |
| **Time lag dir** *(directed) - not merged here!* | p = .373, ATS = 1.47 | p = .982, ATS = .26 |
| **Time lag abs** *(absolute, un-directed!)* | p = .677, ATS = .57 | p = .794, ATS = .43 |
| **Switching** *(merged but based on directed data!)* | p = .709, ATS = .47 | p = .463, ATS = 1.07 |

**Tables A.II.2** Statistics of the MANOVA and individual measure ANOVAs of movement coordination in the MirrorGame. p-values are FDR corrected for multiple comparisons. Note that leader-follower trials (that is, trials in which either player 1 or player 2 was instructed to lead, and the other player to follow, respectively) are merged for all measures but directed time lag.



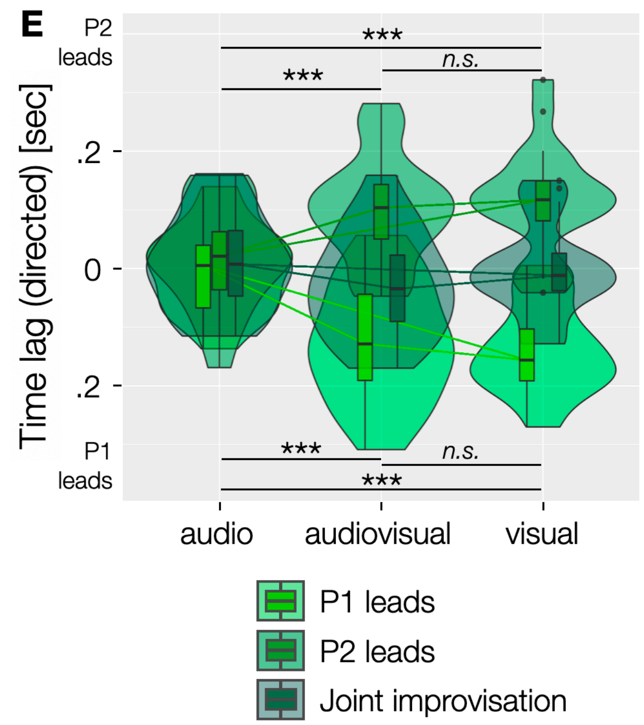




**Figure A.II.1** Significant interaction effects of sensory feedback modality and leadership instruction in the family of movement coordination measures. FDR corrected p values are indicated by *** (p < .001), ** (p < .01), * (p < .05), + (p < .10) and n.s. (p >= .10) for post-hoc pairwise comparisons - the lines below the symbols show which two sensory feedback modalities were compared. **Figure A.II.1 A to E** Interaction effect displayed for position difference, synchrony, absolute time lag, switching and directed time lag.

**Supplementary Materials II.D**

**Thematic Content Analysis of the individual interviews** - example quotes from the largest theme '*Orienting, figuring it out*'

| | ***Code*** | ***Example quotes*** |
|---|---|---|
| **Personal, social interaction** | *getting to know the other* | "*overall - exciting, how one can try to read the other, or anyhow have fun together!*", Pa9P2; "*noticing, which moves he makes. or, to which of my moves he responds*", Pa9P1; "*one really got to feel closer, time and again, over time and the trial runs.. so that one could sense the personality of the other a bit*", Pa12P1; "*curiosity - how not-calm is my partner, in this moment when I am so calm and not-moving?*", Pa12P2; "in *trial 22 - I felt she really sent me around - but I liked it, and then I thought, ah, maybe she is more the visual type? I think she also mentioned in the joint interview that she doesn't like it when there are no visuals..*", Pa13P2; "*for sure a learning process throughout the time - what works together? I did something more playful, and then I noticed, ok, it really works, she did try to follow me!*", Pa16P2; "*yes, there was also an interesting point - the intimacy between, like me and someone I've never met, like, only through this game for two hours or one hour. I don't know, it was actually.. it went really fast for me. So yeah, it was just very, a completely new way to get to know another person. And it was not bad, it was actually cool*", Pa26P2 |
| | *balance - integrate with other* | "*it was also exciting when the other escaped the pattern - what now? how do we figure out what to do next? […] find out what she wants - also watch out that I make some proposals myself.. both*", Pa9P2; "*I noticed a moment when he - was waiting that I join, and then, ah, she won't do that. and then, this.. (other mode).. but it still got to something coherent. So, the irritation passed quickly... there remained a bit of wonderment.. I don't know.. can one do that? But then it did enter something playful*", "yes, we got closer to creating together!", Pa9P1; "*equitable - in the sense of both enjoying. harmony is important, but not too much also - else there is no reason to interact??*", "*or, 'I hope you notice that we can produce tunes? so, what do you want to do now?'*", Pa13P2; "*You want to collaborate - not disappoint the other.. you don't know how the other will react, what she will think.. given all this, it is difficult to really move away.. but, one still has to try now and then :)*", Pa18P2; "*third block, joint improvisation, first 10 seconds: like a test moment - who leads? what's happening? are we going to settle on a known pattern?*", "*it was different each time - can't say why.. sometimes it worked, sometimes not so.. like, both are standing still - will you indicate directions, and then me, or, reverse? WHO makes the proposal? How do we resolve the lack of clarity?*", Pa18P1; "there was this question about creativity - so, you tried to do something new - but, you wouldn't want to confuse your partner either - I think we did this quite well", Pa22P2; "*I felt that there was this kind of tension - to always find the balance. When I was like this, he was like that. So, if I was very logical, then he would be rather intuitive, and vice versa. And when that was the new logic, then, back to analytical mode, focusing on order*", Pa25P2 |
| | *self-reflection* | *"towards the end I dared a bit more, to say 'no, there was no special moment', before, I was a bit under pressure.. also, three times I thought, ah, she has to wait so long now because I am writing something down..", Pa13P2; "sometimes it was surprising, about my partner, I felt like I could read his brain! Or, also, to observe my ego or that 'wanting to control' inside me - that I don't always have to.. but sometimes I can also… be patient.. I thought, he was also good, my partner, so, I felt like I can find more balance, with myself, in this experiment... I also liked the name - 'mirror' .. :)", Pa16P1;* |
| | *offering opportunities* | "*I felt like we thought a bit about each other's preferences, after the interview.... like, giving space to that.. I wanted more calm movements, creating melodies etc, he rather wanted more extreme movements..*", Pa18P1; "*I am supposed to follow her but she stopped moving. so I can move a little at the center to play some nice music. thanks.*", Pa19P2; "*After we talked, it was a bit boring, but then I attended more closely to the sound - because you had asked about it, and it was what he had focused on… I had really neglected the sound a bit..*", Pa22P1; "*Or, when I felt like she was always with the flutes - I was like, ok, I'll move over there so we can do sth with the flutes*", Pa26P1; "*Oh, I move too much. So I just offer her to move. So I just stopped and waited for her to move. And then I followed*", Pa26P2 |

| | Code | Example quotes |
|---|---|---|
| | *disagreement* | "I also wanted to do myself - sometimes.. I thought, no, not like this. For example, we were some different places, we really didn't want to.. maybe we were both waiting that the other comes.. like, tomahawk? (declare war)", Pa16P1; "sometimes we moved from sliding to tapping, but sometimes the partner would boycott - not move along..", Pa25P1; |
| | *other is..* | "*towards the end of the third block, one time, we were very synchronous, and he noticed that I stopped, so he waited, too. somehow considerate. and.. he had fun! so, didn't really know because we didn't really look at each other, but, I still knew that.*", Pa12P2; "*more playful, because I noticed she jumps a lot. especially in the beginning - she didn't seem so much like a playful person before.. with her answers in the joint interview, I noticed she likes to drift off.. somehow active in the arts world.. rather intuitiv over all?*", Pa16P2 |
| **Modes (evolution) of play** | *associations* | "*or another time, we repelled from each other, as if we were magnets..*", Pa9P2; "*like basketball - with attack and defence, where you nearly mirror the movement of the other, always trying to mirror the ball..*", Pa12P1; "*that trial started by us moving onto opposite sides - and then, ok, that's the point we always return to. reset. yes, and then we always did stuff, waving, parallel, or mirroring (opposite).. and then we would return to our home bases. and once she would take me to her base, but, at some point I had to go back home to my side, you know? yes :)*", Pa13P1; "*a piano piece, tuning a radio, associations like that..*", Pa16P1; "*Interesting that we both knew what song it was just by visuals and rhythm. I could imagine the music*", Pa19P2 |
| | *explore, experiment* | "*there were also times when we were more creative*", "*faster and faster until it turned a bit chaotic in the end*", Pa12P1; "*sometimes also we both do something, and somehow we get together in that - like, often in the beginning of a trial - hey, I am here, yes..*", Pa12P2; "*I didn't even think of being more creative, jumping around - that was THE big surprise for me in the game..*", Pa16P2 |
| | *patterns* | "*so the first I remember - visual, joint improvisation - we were on opposite ends, and then I mirrored her, and then I noticed she understood what I was doing, and then she challenged me - faster… and at some point she mirrored me… then we kept on swapping roles… without clarifying somehow, or planning, I mean - we moved for a while, together! like a little choreography or so..*", "*for example, I move, and she maintains a certain distance, or.. we stick to many or fewer sounds*", Pa9P2; "*jumping from one side completely to the other, or, jumping fixed shorter distances. We varied a bit there - jump, a little movement, jump, .. or, instead of jumping in a row, jumping back and forth.. or.. all those things, sliding… and that short shaking movement, we also did that more often..*", Pa12P1; "*for the latter part tried to stay at the middle until the harmony faded away and get back to the centre again*", Pa19P1; "*then we both stopped, to appreciate it for a moment. that almost felt like a perfect cadence, like the end of a piece*", Pa19P2 |
| | *intuitive, rhythm* | "*Repeatedly crossing, finding a rhythm, playing a game - doing something surprising, not so much planned. Strict following would have been very focused - this was more intuitive*", Pa9P1; "*In the end I closed my eyes for a whole trial - so like very short open some time in the middle but..*", Pa16P2; "*even for the part where there's only visuals, no sound. There is actually sound because we hear the tapping happening. And when there is rhythm, we still hear that. So it was quite apparent even there's no sound of the headphones and then that also played a part.*", Pa19P2; "*I think this.. darkness… when I made a mistake - it was not so 'in your face, in front of me' .. as if I had closed my eyes, I could really rely on my musical intuition to guide me, give up control. With visuals, that didn't work, something was reactivated too much somehow..*", Pa21P1; "*So I always tried to establish patterns - tapping three times, slide to the other side.. towards the end I sometimes stopped moving.. and she actually came over.. or.. skills games, catching.. certainly a learning process throughout the time - what works together, and, patterns*", Pa16P2; "*with the sounds.. we often paused, when I had the feeling that we both liked it...*", Pa21P2 |
| | *repeat, train other* | "*and then I would know if it was that - when she would repeat her action*", Pa9P2; "*later, she tried to condition me - so, you always do the same sequence of moves, and at some point you expect the other to know, automatically, what one does, even without one doing it*", Pa13P1 |

| | Code | Example quotes |
|---|---|---|
| | *search mode, focus, listen* | *"search mode I'd say, was, you know more focused, trying to recognise what she does - highest level of attention"*, Pa9P2; *"Then.. when I had provided some input and we had developed some material.. then I was more open to listen, hear from him, follow what he suggests"*, Pa9P1; *"so there were times when we were really slow and precise"*, Pa12P1 |
| | *sync mode* | *"especially with only audio - did we manage not to create any noise sounds?"*, Pa9P2; *"very good connection - it was very slow.."*, Pa16P1; *"staying together, harmony"*, Pa16P2; *"in the first moment it was surprising - the same idea, but implemented differently - once with tapping, once with sliding. I think I also selected 'happiness'/'lucky' in the corner of the magnet board where we reported our feelings. Coming to think exactly the same, not just once, but several times, yes. :)"*, Pa12P2 |
| **(Not) Following & follow-ability** | *anticipating* | *"in trial 23, e.g., I felt like I could predict what happens next, even though it was not only simple moves, that was fun somehow - slightly more complex moves, that they would come now.. :)"*, Pa12P1; *"I wanted to let her follow, so that she can anticipate my moves"*, Pa13P2; *"simply trying, where could be the next.... if you would figure it out, and be able to join, that was fun"*, Pa22P2; *"towards the end I had a feeling for where we would move - even without a familiar pattern"*, Pa26P1 |
| | *(not) being able to follow* | *"in trial 13 I jumped really far distances (that was probably too much) - now I did it with smaller distances, once he would have found me, like, 1cm or so.1cm 1cm, maybe 3cm..."*, Pa12P2; *"trial 10, audio only, following - I somehow missed her.."*, Pa13P2; *"it was hard to follow him - I know what his motion on the slide bar was but finding the synced point was difficult because he kept sliding left and right. even i tried to focus but its still hard to adjust immediately"*, Pa19P1; *"follow-ability - like when dancing. As a man, you have to learn - where can I activate the body to signal direction, when can I dance a figure, so that both can already anticipate what will come..."*, Pa25P1 |
| | *listening, accepting, following* | *"it was relaxed when my partner was leading. I knew what I had to do"*, Pa13P1; *"trying to follow as exact as possible"*, Pa13P2; *"following, open, yes, now I go where you want to go"*, Pa18P2; *"a very clear unspoken rule kind of formed and the time of searching what my partner was doing was direct"*, Pa19P1; *"usually one person followed, and, I felt that we adapted really well to the other..."*, Pa21P2 |
| | *interrupting the flow* | *"when the other escaped, broke the pattern"*, Pa9P2; *"we were very synchronous - I sort of interrupted that with a jump"*, Pa12P1; *"following less also.. sometimes I wanted to do myself - I thought, no, like this it doesn't work"*, Pa16P1; *"you don't want to be doing the same thing the whole time - so we did a pattern for a couple of seconds, then switched to something else"*, Pa22P1; *"sometimes hard to know, when to stop? didn't want to break out"*, Pa26P1 |
| | *not (being) following(ed)* | *"at some point you felt challenged - so, I tried to read and understand her.. at some point I noticed she liked to jump.. in the beginning, a real task - so, not always, but.. towards the end she did also follow"*, Pa16P2; *"a moment where I was supposed to follow her. I don't follow her anymore. Because, yeah, I just feel like doing something different. Yeah. Okay. No, I don't follow"*, Pa19P2; *"I followed but not much. the goal is FUN"*, Pa19P1 |
| | *(no) performance pressure* | *"continuing.. seeing something cool.. affirmation.."*, Pa9P2; *"I know that I was always overwhelmed when I was assigned to lead"*, Pa13P1; *"leading is also ok, but also responsibility to not be boring"*, Pa13P2; *"leading, ok, now I do something interesting - but, didn't always work"*, Pa18P2; *"she seems unimpressed"*, *"I played 'mary had a little lamb' with the distance sound - she laughed"*, Pa19P2; *"in audiovisual, I felt observed somehow not really free.. also quickly had the impression that it would be perceived as boring, because you could 'see' it somehow"*, Pa21P1; *"on the third round, I got a little bit of pressure that I have to make a pattern. Because it was the moment that I realised that Oh, I we, after the trial we also make a rating / impression of it, how creative it was. Yeah. And then also, we talked about the pattern. how interesting it was. And I liked that when she said that it was really cool. Yeah. So I just wanted to make her happy on the next round. So yeah, I got some pressure"*, Pa26P2 |

| | Code | Example quotes |
|---|---|---|
| **Doing something interesting** | *constraint* | “*We try to have fun with just those constraints that we can only like slide the bar, that's the only thing she could do - I would say is an experiment about interactions and how people can make some creativity under a large constraint: that we only can move a slider*”, Pa19P2; “*that’s why I tried to do something different - the game is rather limited.. even though.. maybe there are more options that we didn’t explore..*”, Pa18P2; “*so, when there was only audio, or only visual - for me it is like.. so when I am healthy and I can just do things, effortless, and, I feel a little bit stupid, silly. but, when I am a bit sick, then I just feel something else does something, that really matters to me, and, it inspires me a lot. I think*”, Pa26P2 |
| | *creativity* | “*ok it’s several things - feeling free from.. ‘I don’t have to be right/correct’.. and because of that, I was more in my body - the visuals, the movements of the dashes, as if that was two balls inside me - sensing it like that, more haptic, plastic*”, Pa9P1; “*creating sounds together, or visuals, depending on the creative motivation of people. doing something creative together, with an unknown person*”, Pa9P2; “*and staying creative - not standing still in the same. try something new, or, bring up old patterns again*”, Pa16P2; “*when we were not instructed to lead or follow, that created the space for us to be creative*”, Pa19P1; “*there was also this question, ‘creative?’, so, you tried to do something new because of that, and then you also didn’t want to confuse the other, so - I think that worked quite well!*”, Pa22P2 |
| | *waiting for the other to contribute* | *“then I felt that she was following too much. I would have wanted more input from her, so that it is more exciting”*, Pa13P2; “*I tried to lead a bit and see if he follows and I was hoping that he would stop at one point so we could create sth other than the harmony*”, Pa19P1; “*sometimes waiting for the other to perform*”, Pa19P2; |
| **Proposals, ideas** | *making a proposal* | “*I wanted to contribute, set points - explore different possibilities..*”, Pa9P1; “*sometimes I have my ideas and I contribute*”, “*someone just proposes something*”, “*the way to to catch her attention, I think that didn't really change a lot. We just did whatever we think of*”, “*i realised we can jump to places instead of sliding*” Pa19P2 |
| | *recognising proposals* | “*does she really want that I just follow? or, make a game of it..*”, “*does she want to tell me something with this? trying to empathise…*”, Pa9P2; “*all the better, playing again after we talked in the joint interview - maybe before we could guess what was going on inside the other’s head, but now, it was more clear, you could recognise it more directly*”, Pa12P1; “*I think she heard it*”, “*she will recognise. Yeah. And the other way around as well. Sometimes she does something. And then I see that. Yeah*”, Pa19P2; “*this was like during my improvisation class, when I could trust the group - so I could feel that yeah, she's really good at this, she will follow me and I just did it, didn't really hesitate, and then she also followed that and the next trial we had like a practice moment, that was really cool*”, Pa26P2 |
| | *co-create, pick up ideas from each other* | “*so, she did that, in trial 5, and then I tried to continue that in trial 6..*”, Pa13P1; “*so it's more about how I could react to his motions and how to react with his idea in terms of visually and audibly*”, Pa19P1; “*I wanted her to do what I did before - I somehow tried to signal that, first didn’t work, then, we swapped roles, even though I was supposed to lead, I think, so - cool!*”, Pa21P1; “*by adapting to each other, we often adopted behaviours from each other. so, not special strategies, just taking on things. or, doing the opposite..*”, Pa21P2 |
| | *failed proposals* | “*sometimes I missed her meaning. She said she played this song 'dada..' - but I didn't see that at all*”, Pa19P2; “*I was playing another song piece to see if he follows. and I don't think he did*”, “*I was playing 'into the unknown' but it seemed like he was not able to follow it / get what I was playing*”, “*what he was tapping for me was quite random because I couldn't find the pattern of it. and his motion after the long sudden stop was hard to anticipate*”, Pa19P1 |
| | *no more ideas* | “*the patterns (visual) were depleted*”, Pa13P2; “*don't really know what to do -.- I am bored with the harmonies and wanted to create sth else but I dunno what to expect from him*”, Pa19P1; “*I literally just ran out of ideas*”, “*again, a bit boring - jumping around a lot but we both ran out of ideas*”, Pa19P2; “*we didn’t do patterns for long.. often it worked well (to swap), sometimes we had to do a bit more.. stick to it.. in the end we ran out of patterns.. ^^*”, Pa21P2; “*third block - felt restricted - we did everything there was to do. tried to find something new but really couldn’t. yes, bit boring*”, Pa21P1 |

## APPENDIX III

**Supplementary Materials for Epilogue 2, the Playful Academic**

A. *The Protocol for the Playful Academic*
B. *Guide for facilitators*
C. *Thematic content analysis of participant reports*

**Supplementary Materials III.A**

**The Protocol for the Playful Academic**

This protocol aims to bring together the different ways in which we are present to and involved in our work: from the space(s) that we inhabit, to our bodies, the aspirations and questions that motivate us, as well as the social and larger professional dynamics that we form part of. It invites you to imagine, reflect and populate your work, together. In spite of the care this box holds for playful collaborative work, we cannot (and would not) determine how exactly you respond to this process. We encourage you to take the freedom and responsibility to pause, or to ask for a moment for refection with (one of) your colleagues whenever you feel the need to[11]. Likewise, we are curious which other directions you might want to explore - the box is an evolving collection of suggestions and material.

[11] Allocating the first 10 minutes of a meeting to 'check-in' in pairs (5 minutes to share for each person how they arrive at or what they bring to the meeting today) can support grounded and productive group work.

*One night I watched my thoughts*
*piling themselves up all around me.*

*My mind built a house out of all those thoughts - then filled that house.*

*Soon it was a whole city.*
*A whole world.*

*Oh, my beautiful, beautiful thoughts.*
*Who will look after you after I'm gone?*

*I swear I weep.*
*I weep for all of you.*

*Do you really want to be free?*

*Are you ready to leave behind*
*your precious little houses -*
*make your home everywhere?*

*It's not as hard as you think.*
*First stand up.*
*Then walk out the door*[12].

[12] Adapted from *The First Free Women: Poems of the Early Buddhist Nuns* by Maty Weingast, Bhikkhuni Anandabodhi.

**Activity 1: Drawing In Circles**

This activity can be used to explore a sense of shared belonging and decision-making. We also found it a lot of fun - an ice-breaker before starting to work together.

You will need a large paper/surface, colored pens (one color for each), a comfortable space to sit/lie/stand so that everyone can reach the workspace.

The form of the game is as follows. We give you a limited set of painting gestures: circling, making dots, and drawing parallel lines. Imagine them as continuous gestures: Repeat them without interruption until you switch to another gesture or a conscious moment of pause.

Gather around the paper/surface. In the beginning, stand still and silent. At any point, anyone can pick a pen and start performing their choice of gesture. As soon as that happens, all others join that person in performing the same action, until any of you decides to change to a different gesture, or pause. The trick of the game is that whenever one person takes initiative, all follow. Quickly and organically.

Notice when the game feels out of bounds. Need a restart? Express your desire to stop by simply pulling out of the circle. The basic idea is to invite simple expressions and interpersonal awareness.

***Possibilities for variation #1:***

If you have enough space and moving is not a problem, the exercise can also be performed as a movement session. The paper would correspond to the floor, and the painting gestures to different gestures (moving the hands or another body-part to form a certain shape, or moving a certain and not other part of the body, ...) or ways of moving around the space (slow-fast, upright-crawling, …). This setup could also serve as an intermediate one between the original version of activity 1 and activity 2, transitioning between inner and outer/social focus while moving in space/to write.

Alternatively, you could use body percussion: the paper would correspond to the surrounding (sounding) environment, and the painting gestures to sounds produced by clapping, rubbing your hands, vocal sounds, steps on the floor, etc.

For online, digital sessions, different drawing, sound production, idea mapping, or movement emulation software could be used. For example: Aggie.io / Mozilla Hubs / Zoom / Soundtrap / Coggle.

**Activity 2: Writing from Toe to Ceiling**

Find yourself in a familiar (hand) writing position, bringing or imagining any material you need to write. Now scribble (doodle, draw. Don't think about what you are 'writing').

As you scribble, explore your sensations while focusing on different body parts. Start from the fingers holding the pen. How - if at all - do you feel your writing in your fingers, wrist or elbow? Do you feel movement in your shoulders and back? How far does it reach? Is there any sense of movement in your hip? Your knees?

Take a minute simply to rest your attention on one part of the body, while you are writing.

Can you initiate a scribbling movement from here? (Focusing on initiating movement for example in the upper back - can you do that, and it just so happens that you scribble?) Or could you combine these places, and initiate the movement from between your fingers and, say, your upper back?

Also check in with your posture and environment. How are you holding yourself? What could you do - if anything - to make yourself more comfortable in your activity? Where are you with respect to walls/boundaries, furniture and others present? What is happening, besides your own exploring? Notice if the room and the others affect your experience and activity.

If you feel like it, find a different posture or place to perform your writing exploration. You could also choose a different pen or switch to writing on an imaginary keyboard. Repeat the exercises above. Do you notice any differences?

**Figure A.III.1** Writing from the back of my head? Exploring activity 2.

When you are ready, take a moment to finish your exploration, then come together for the next activity.

Would anybody like to share something with the group?

***Possibilities for variation #2:***
Instead of writing, any other activity can be performed 'From Toe to Ceiling'. For example, if you are preparing for a public presentation of your research, you could apply the same steps to "scribbling" with your voice. Start talking with random syllables. Get acquainted with how your speech apparatus behaves and how it feels to talk from different parts of your body, etc. Similarly, if your academic work involves technical operation, laboratory experiments, or musical performance, you could apply the same principles to these practices.

If the idea of 'writing/speaking/.. from a particular body part' is at first hard to grasp, you could exemplify it in a simple movement exercise: lie down on the floor, lift your hands with straight arms so that they meet in front of your chest, pointing to the ceiling. Now, keeping your arms straight, slide your hands' surfaces across one another. As you do this, you will likely notice movement in your shoulders, where your back touches the floor. Can you initiate the sliding movements of your hands *from this area (back/shoulders)*?

**Activity 3: Each of Us and All Together**

Here we invite you to set and share your current context and perspective. We start with individual reflection and bring them to the group in a sharing circle. Here, it can be helpful to time your turns at reflection and sharing - perhaps one person from your group takes this task, simply keeping an eye on time, or using an app that makes a soft sound to mark the beginning and end of the set time.

To begin this activity, take a look at the set of questions below in *Table AIII.1*. We recommend that each of you finds one question. The question is meant to lead you into reflecting on how different aspects of yourself and context relate to your work. The set covers what we found most important. It is neither exhaustive nor particularly 'right' - we include it here to inspire your inquiry.

Take your time (about 5 minutes) for individual reflection on the question that you will offer (to yourself, and later to the group).

Importantly, get concrete: As you sit with your question, notice which *specific situations and experiences* come to mind. What is it about them that matters to you and the work you are engaging in? If you feel like it, take a few notes (draw, visualise, move - whatever helps you stay with your question).

When the time for reflection is over, find your way into a 'listening circle'. One idea inherent to such a circle is that it offers a moment of attention to each of our stories. Physically sitting at equal distance and level can facilitate this quality of welcoming and listening. Introducing something -

**Table A.III.1** A Collection of questions to support personal inquiry.

| *Category* | *Questions* |
|---|---|
| **A. Personal background and motivation** | • Why am I engaging in this project? How is this collaboration meaningful to me?<br>• What are my needs and interests?<br>• Which stories connect me to this project?<br>• What is it that I seek to engage with?<br>• Which particular aspects of the project connect to which particular aspects of me, today? |
| **B. Body and environment** | • What is the position of my body? What does it feel like?<br>• Where in the room have I put myself? What is present from my perspective? What do I sense?<br>• Am I comfortable, vibrant and available for this project?<br>• Is there anything I want to move or change in my body or space to feel more comfortable, vibrant and available?<br>• Spend a moment thinking about the circumstances that allow you to be here - this can be people, the weather, good food, an inspiring teacher or an unforeseen event. |
| **C. Social relations and group activities** | • Who else is part of this project? How does my relationship with them feel right now?<br>• How do we take care of this project together?<br>• Remember a specific moment: what do I notice or value about my contact with others?<br>• Do we invite differences in our modes of engaging and relating? Different perspectives, needs, curiosities?<br>• What quality of dialogue do we invite?<br>• How do we reflect on and make decisions together?<br>• How do we offer time to what arises between us? |
| **D. Traditions and transitions** | • Remember a moment of working on this project that you really enjoyed - what happened there?<br>• Remember a moment of working on this project that was difficult for you or the group - what happened there?<br>• What do you want this project to be? What has this project produced for you? Which new plans, possibilities and questions have arisen for you through this project? |

such as intentions, dedications (verbally) or an item (physically) - into the centre of the group can likewise serve this idea. It is a way of jointly creating the context and purpose of a meeting.

We furthermore find the following advice useful. Before you start to share from your reflections, you may take a moment to read it (out aloud):

- When speaking, focus on your personal experience: describe its quality, avoid generalising.
- When listening, witness what comes up for you in response to what is being shared. Try to let go of any urge to clarify, understand, judge (positively or negatively) or set right.

- At all times, sense what is happening to you *and* to others in the group.
- If you feel it is needed, take actions to turn the situation into a more welcoming, more supportive one.
- Sometimes silence is very helpful to communicate with ourselves and others

Now, revisit your notes and thoughts from the individual reflection. Is there something you learned about your motivation, practice or environment? Anything you would like to share with the group?

One person begins. (If you keep time, set for example 2 to 3 minutes for each person). Give a clear signal as to when you have finished sharing. To know who is next, simply go around the circle, invite another person by their name, or use a talking piece that you place back into the center, for anybody to pick it up (or its online variant: to mute/unmute yourself).

When everybody has had time to share, check in with the group if there is any interest in sharing more. You might also do 'another round' of time to share for each person.

***Possibilities for variation*** *#3:*
You could vary this activity by *how* you select the question: whether you limit it strictly to one question or allow merging/several questions for reflection, as well as whether you pick it consciously, or select at random. Similarly, you can either specifically define the project or area of (working) life to which you want to apply your questions in advance, or not. Naturally, feel free to expand and modify this set of questions according to the needs and issues that emerge in your group.

**Figure AIII.2** Materials and traces from Activities 1 to 4. AL exploring the protocol with two colleagues in Hamburg (Lissa Streeter and Angela-Mara Florant, see thesis *Acknowledgements*).

**Activity 4: Triangulating Space**

As in the first game, you need colored pens, a large paper, and space to gather around it. This time each person picks one shape that will be his or hers throughout the game - for example one person picking circles/ovals, the other rectangles, and the third one triangles.
Now take turns at adding/drawing your respective shape to the paper, one instance of each figure per turn - varying its size, orientation, and position in relation to what has already been drawn.

Take as much time as you need for each action. Consider perceiving the paper as a painting, and notice how the points of fugue (recurring patterns), accumulation, rhythm, color, grading, and other formal aspects vary every time a shape is added. Also notice the effects of another person's drawing action on you. Can you, through your next action, bring this to play out on the paper?

Notice when you feel that you are done.

***Possibilities for variation #4:***
Similar to Activity 1, you could replace paper and pen by moving yourselves or objects in and out of a designated space. Any substrate or platform can work: you could also iteratively record a sound to which each person can contribute with a specific vocal gesture, or perform a 5-minute improvisation that starts very simple and iteratively grows to include further actions. If you meet online, you could again use either of the collaborative software tools we list above with Activity 1.

**Figure AIII.3** Perspective shot through Activity 4 - this time triangulating space within a three by four meters area of lawn and a wider range of materials than paper and pens only.

**Activity 5: Reading between the Concepts**

With this activity, we invite you to fully commit to a text by paying detailed attention to how you subjectively experience it. New facets of this text might become apparent, opening other avenues for future research.

Choose a short text that seems important for your common (writing) endeavour. Examples could be: a paragraph of your own article in the making, a quote you are considering to use, a paragraph of previous writing from either of you that could play into the current process, etc. We suggest not more than 5 sentences to begin with.

Pick one of you to read the chosen text aloud. It does not matter who it is but it is a good idea to change the reader from session to session. You can choose to only listen, or to also have the text as a printed version available for each of you. We recommend, however, that you do not read ahead.

Each of you, grab pens and paper. Feel free to use a large format of paper and multiple colors/types of pen.

Start reading/listening with great focus: one sentence at the time, pay attention to your experience while reading/listening. By experience, we mean your thoughts, feelings, mental images, bodily states etc. Notice what you live through while reading/hearing this sentence. Feel free to write notes, paint, sketch or use whatever connotation method helps you to describe, remember or manifest the experience.

When you are ready, proceed with the next sentence. Once you finish taking notes on your experience of the last sentence, we encourage you to enter into a dialogue as a group. You could collect notes on a board visible to all, to support yourselves in and keep track of the idea creations that might follow from this activity.

In this process, you might notice unique experiences and similarities across all or most of you. If your experience was different from your colleagues' - can you read the text like they did? You might go on to discuss if your experiences fit the purpose for which you (wanted to) use the text in your work.

Can you generate a variant with a different effect?

How was this like for you?

***Possibilities for variation #5:***
For each of you to be able to fully focus on listening, you might record the text beforehand. And again, the attitude of slowing going through your work, step by step, can be applied to other material: from the series of points you plan to make in a meeting, presentation or paper, to any work-related progression of experience (as you read an email, type a sentence, watch an experimental stimulus, travel to you work place or prepare yourself a coffee).

**Activity 6: Creative Nonfiction**

This is an activity to facilitate play on expression. It might be a way for you to think differently-structured, more intuitive, or to start your thinking-process at an unusual point.

Choose material you want to write with (or about) today - it could be material from the reading game above, or any other ongoing work, such as an experience from one of the other protocol-activities.

Try to re-write/extend it in one or all the following ways:

a) Think about the worst enemy of (your perspective on) the writing material. Write about it from this (antagonistic) perspective.
b) Take a book, open it on a random page and take the third sentence of the page. Use this as your starting sentence for what you write.
c) Write it as a confession.
d) Think of somebody whose writing style you adore (can be a scientist, novelist, friend etc.). Try to write it like she/he would.
e) … any-all-else you think of to spark your writing into a totally different direction! :-)

Decide how much time you want to devote to this, today.

When you are done: check in if the group needs a break, before you go into a final 'harvest round' of witnessing the moments that stick with you, or sharing what you have learned and experienced with the group: a short moment to stretch, fresh air, a bit of movement, close your eyes.

***Possibilities for variation #6:***
The list of possible variations is endless - find diverse starting points, characters and roles that speak to you or that make you take on a very different perspective. For more inspiration, you could also have a look at creative writing prompts online.

**Activity 7: Diamonds in the Raw**

What moments of the last hour do you treasure?
What is present for you now?
What, if anything, do you take with you out of this room?
What would you like to unpack in the next meeting?

To share and hear thoughts and impressions from the group, we recommend the form of a listening circle. If you decide to use it, take a moment to remind yourself of the form (see our list of advice in activity 3), find a time-keeper and set how much time you want to give this. Maybe give yourselves a minute or two for individual reflection, before you start sharing.

***Possibilities for variation #7:***
Beyond the verbal sharing and written notes, it can be nice to have a material trace of your explorative process. A physical memory of something that came out of your time together - one idea might be the drawings from activities 1 and 4. They could live on as a postcard.

**Figure A.III.4** Collection of additional materials to be used as part of the activities.

*~ Thank you for opening this box of treasures.*
*We hope it can be your ally in many academic adventures to come ~*

**Supplementary Materials III.B: Guide for facilitators**

Below you find advice to help you use and adapt the protocol to your concrete context.

1. *When to use (activities from) the protocol?*

Overall, the activities we provide in the protocol invite you to take the time to arrive more fully to the material, physical and social environment of your everyday work, and thus discover it from a new perspective. Through its overall structure, it takes care of a diverse but nested exploration: it not only supports you to venture onto new grounds, it also equips you with tools to reflect on and integrate these experiences. As such it could be used to start a week, a day or a specific working project or session with a group, but it might also become part of a more regular routine.

2. *How much time does it require?*

To run the entire protocol we assume you need at least 2-3 hours. While we recommend to take this time once in a while, of course it is not always possible to devote several hours to explorative collaboration. At other times, you might therefore pick one or several of the activities, relevant to your current work, and use that to begin your meeting. By itself, and as a reminder of the entire 'family of activities' from the protocol, this can serve as a work-related but personally grounding check-in. When you explore with the protocol, it helps to set a time-frame that acknowledges everyone's needs and interests. Such a frame can also amount to 'we are open to how long this takes' - what matters is to set and subsequently take care of this frame, together.

3. *Which (order of) activities to use?*

We consciously chose the order and range of activities: the protocol begins with activities that ease you into working together and make you aware of your body, environment and fellow researchers. It proceeds with a set of questions to reflect on intentions and motivation, as well as tasks for creative reading and writing. Throughout the protocol, we invite moments of short sharing or check-in rounds. While we found this progression helpful, you might want to vary order or select single activities according to your needs.

4. *How to vary the activities to prepare for a specific task?*

The version of the protocol we offer here is particularly designed to facilitate playful writing. However, below each activity we provide a box with possibilities for variation - to cater towards other academic tasks or allow non-repetitive reuse of the scores over the duration of a project.

5. *How to prepare the room and the group?*

We recommend that you think about the level of introduction to the purpose or origin of the protocol / individual activities that is appropriate in the particular group you are working with. What does everyone need to be ready to start? In case you are hosting the meeting space: what should be available in that space, to support you and everybody else? In case the event is online and everybody is in their own space: in which way should they prepare (have water available, be undisturbed, which tools do they need..)?

*6. Who should facilitate?*

We suggest you take turns (at co-)facilitating, so that each of you has the chance to gather experience as a facilitator. This will also help you to learn to take care of your work as a group, together. Familiarity with the experiences you are facilitating can put you at ease and therein enable you to respond to the group in the moment - as such, consider which activities you might feel most comfortable with and begin by facilitating those.

*7. How to cater for spontaneous needs and possibilities?*

It is our biggest intent to stress the importance of sensitivity on all experiential levels. This of course applies to the facilitation of this protocol, too! During the session, try to be as neutral as possible and let the group find its own pace into the set of exercises that you have prepared: try to stay open to knowing *now* what is the right thing to do or say. The protocol is in important ways designed to lead us into uncharted territory. Our understanding is that presence and readiness to respond to unexpected courses of events are based on clear communication, regular check-in with the group, and the ability to stay calm and available to yourself *and* the group throughout the process. Trust that time will train your instincts on when to shift the task or setting. Consider your own and the group's experience your best teacher.

An image we find useful is that of a buffet, festive space, or a color palette and canvas: consider what is needed in advance and prepare with care, but then let go and engage with the dynamics of the moment, instead of clinging too much to your plan.

*8. How to keep eyes and ears open for everybody's needs?*

Working with the protocol can create intimate social spaces: moments in which members of a group feel at ease and thus ready to depart from long-time familiar territory. This is further encouraged by the opportunities for fun, creativity and surprise. Moving in unexplored, unfamiliar terrains, however, can also be uncomfortable or difficult, and confront us with our vulnerability. Since we are in a group process, it may be difficult for the facilitator to decide: am I ready to support the group in listening to all of us wherever we are? Such moments of tension can become important learning experiences and potential sources of strength for a group, but they can also take up more time than you want or anticipate. We take from this an interest in activities that look deeper into group dynamics[13]

Since every group is different and continues to evolve over time, we suggest that you use the questions below to inquire about your experience with the protocol/activities. The qualitative analysis approach that we used for our own evaluation might help you - find it below in **Supplementary Materials III.C**. No matter whether you use the questionnaire for formal or

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[13] Find a list of resources that we consider useful at: https://wearethefuture.net/social-moments/

informal evaluation - making the protocol useful can in itself be a fruitful process of collaborative exploration.

i. Please take a moment to think back to the experience. Do you recall any striking moments?
ii. What did you find challenging, irritating or similar? What did you find especially valuable?
iii. If you engaged with the protocol just recently: How do you think it might affect your study, research or work? If you engaged with it already a while ago: Did you experience any effects on your study, research or work?
iv. Would you like to continue exploring with the activities of the protocol? If so, what do you imagine?
v. Is there anything else you would like to remark?

**Supplementary Materials III.C: Thematic content analysis of participant reports**

The analysis approach we present here uses feedback we gathered from eight of ten participants who took part in four different sessions of exploring with the protocol. In all cases, the (two to three) participants were colleagues/friends of the facilitating author. Two groups were part of ongoing work projects, two groups were formed specifically for the purpose of testing the protocol. Participants came from different backgrounds including Anthropology, Media Science, Philosophy, Cognitive Science, Physics, Music, Theatre and Design. Due to the Covid19 pandemic, all trials in February 2021 took place online. As suggested in our article, the protocol was adapted for each of these occasions, in particular the time-frame, virtuality of the event and the specific topical focus of the group. This involved using only a selection of the activities from the protocol, as well as adding other tasks.

For example, KH chose to run a version that started with activity 2 (writing from Toe to Ceiling) to facilitate bodily awareness. This was followed by a score lent from Dorte Bjerre Jensen ('*Invite me'*) to create a shared space when meeting virtually[14], and activity 4 (triangulating space), to feel into the collaboration with the others. Finally activity 3 (Each of us and all together) was used to connect the awareness gained for body, space and others with the work-project in focus. In total, this version of the protocol lasted 90 min.

In our survey, we posed the following questions:

i. Please take a moment to think back to the experience. Do you recall any striking moments?
ii. What did you find challenging, irritating or similar? What did you find especially valuable
iii. If you engaged with the protocol just recently: How do you think it might affect your study, research or work? If you engaged with it already a while ago: Did you experience any effects on your study, research or work?
iv. Is there anything else you would like to remark?

Eight out of ten participants answered the questions. Answers were collected anonymously via an online form - the only demographics recorded were participants' education / field of occupation. The collected data was then processed according to the following procedure:

KH went through the data and initially sorted the answers into two categories:

A. Critique and suggestions regarding the protocol
B. Descriptions of experience (lived or anticipated effects of the protocol)

In a first step, we discussed the comments, critique and suggestions to enhance the protocol. For example, based on several positive remarks about 'moments of departure' - instances when the group discovered additional dimensions or alternative versions of the activity and started to behave in ways that were neither explicitly instructed nor forbidden in the protocol - we decided to more explicitly introduce the activities as 'play frames' (see above) and added specific suggestions for variation (and flexible reuse) with each of the activities. Another topic that

[14] Find more info about this score at: https://www.eer.info/activities/inviteme-online

emerged was the pace of facilitation and time management more generally, which we pick up in our discussion. Most importantly, we were inspired to add a Guide for Facilitators (**Supplementary Materials III.B**) to assist any group working with the protocol in making the best use of it. Importantly: our data showed that none of the participants evaluated the overall experience as negative. Critique and suggestions were limited to details of the facilitation, as illustrated by these examples.

All statements classified as lived or anticipated effects of the protocol were analysed further: KH inductively developed and applied a coding scheme based on a thorough reading of the responses, following Elo and Kyngäs' (2008) approach to qualitative content analysis. This scheme was then applied by AL on all statements, and the results compared with KH's initial coding. We discussed each of the cases in which our codings diverged, and agreed on one solution or decided not to include the incidence. Table 2S summarises all coded quotes as well as our results: it presents the main categories and subcategories, lists how many of the eight respondents provided answers that were coded accordingly, and provides examples of the related quotes.

Most participants comment on immediate (rather than long-term) effects of the protocol, since they filled in the questionnaire shortly after the exercise (the majority within 3 days).

| Main category | Sub-categories | # / 8 | Example quotes |
|---|---|---|---|
| 1. General evaluation of the experience of participating in the protocol or single activities<br><br>*1.1 Positive evaluation (8/8)* | • Good<br>• Fun<br>• Interesting<br>• Helpful<br>• Relevant<br>• Enjoyable<br>• Surprising<br>• Satisfying<br>• Entertaining<br>• Moving | 4<br>2<br>2<br>1<br>1<br>1<br>1<br>1<br>1<br>1 | "Very good experience, I was skeptical at first (as always) but when you engage in it I think it surprises you." (participant 6) |
| 2. Experienced effect of the protocol or single activities<br><br>*2.1 Effects on mood / feeling (8/8)* | • Feeling less lonely/ connected to the others<br>• Feeling grateful (for the experience and the work with the others in general)<br>• Feeling of discovery<br>• Feeling curious (about upcoming discoveries)<br>• Feeling more competent/ confident/strengthened<br>• Feeling of purpose (of own work)<br>• Feeling of ease and fluency of work<br>• Feeling of surprise<br>• Feeling of joy/happiness<br>• Feeling less stressed<br>• Feeling motivated | 4<br>4<br>4<br>4<br>3<br>2<br>2<br>2<br>2<br>1<br>1 | "It created a different kind of atmosphere and reminded me why I'm here and what I cherish about the group and the work we do, I felt it made a better day for me, I feel happy and less stressed and more of a sense of purpose just now as I write." (participant 5) |
| *2.2 Enhancement of presence / awareness (4/8)* | *..of own body and mind*<br><br>*..of (relationship to your) immediate environment*<br><br>*..of (relationship to your) co-creators*<br><br>*..of (relationship to your) work project* | 2<br><br>2<br><br>2<br><br>2 | "The moment I first recall when thinking back is when exploring the space around me [...]. It sparked my imagination and made me feel very present in the moment." (participant 1)<br><br>"I engaged in the protocol just today and as for now I feel even more connected than before with my collaborators . Part of this is related to the fact that I appreciated to realise that I'm so at ease with them that I can do without problems unusual or possibly intimate things like the exercises we did, so I kind of felt that my group is special . I'm pretty sure in the future this will make me even more motivated to keep working with them and most of all do my best in this work."<br>(participant 8) |

| | | | |
|---|---|---|---|
| *2.3 Experience of greater freedom (5/8)* | .. regarding bodily habits<br><br>.. regarding academic habits and (goal-related) interactions | 4<br><br>5 | "Sudden joy in the first drawing exercise, when I realised how many additional ways of co-creation were possible (e.g. to deliberately interact with the drawings of others); Sudden joy in the writing/scribbling exercise, when my attempts to write with/from a body part (in my case: the right little finger) led from "either wild scribbling or rigid writing" to a joyful flow of writing with greater freedom and artistic fluency."<br>(participant 4)<br><br>"What I found especially valuable was the chance to be given a space to think about an action, imagine and create without the need to produce a product with clear function.<br>(participant 1) |
| *2.4 Enhanced creativity and imagination (3/8)* | | 3 | "I felt creative and entertained." (participant 8) |
| *2.5 enhanced expressive capacity (1/8)* | | 1 | "Sudden joy in the writing/scribbling exercise, when my attempts to write with/from a body part (in my case: the right little finger) led from "either wild scribbling or rigid writing" to a joyful flow of writing with greater freedom and artistic fluency." (participant 4) |
| *2.6 Strengthened collaboration (by for example) (3/8)* | Allowing sharing of experience and giving space for different perspectives<br><br>Rediscovery and reinforcement of motivation for work | 1<br><br>1 | " I found especially valuable that you take a moment to listen to and interact with your colleagues in different levels and it pulled us a bit together" (participant 3)<br><br>"The reading between the lines exercise is good for a collaborative process I think because our brains all work differently and those differences aren't always given a lot of intentional space in collaboration."<br>(participant 2)<br><br>"And: I'm sure this expands my capacities to collaborate with others, to invite joy and curiosity into collaborations ."<br>(participant 4) |

| | | | |
|---|---|---|---|
| *2.7 Elicited reflections (5/8)* | | 5 | "The question round was helpful to reflect on and share how I've personally experienced my own research and writing process." (participant 2) |
| 3. Anticipated effects of the protocol | • Feeling of joy<br>• Feeling of playfulness<br>• Feeling of curiosity<br>• Experience of greater freedom regarding academic habits<br>• Enhancement of creativity and imagination<br>• Enhancement of expressive capacities<br>• Strengthening of collaboration<br>• Eliciting reflections | 1<br>1<br>1<br>1<br>1<br>1<br>2<br>1 | "It [the protocol] might enable me to work with less rigid academic rituals and routines and it might give me the opportunity to more freely share and think together with my collaborators."<br><br>I think it will boost my creativity and help me express things, especially with a sense of playfulness ! I suspect this will make my writings and expressions more "lively" and creative. Bring more joy into my work, and into my felt experience. [...]Over time I expect that my ego-attachment will shrink, and my trust in co-creative group processes will increase." (participant 4) |
| 4. Areas of effect mentioned | • Work<br>• Personal life & beyond | 5<br>4 | "I feel that this kind of exercise affects my understanding of life in general." (participant 3) |
| 5. Interest in further exploration with the protocol | | 3 | "Would very much like to do more of the protocols. I can remember coming away from the last one thinking, More of this! More of this!" (participant 7) |

**Table A.III.2** Summary of results from the thematic content analysis.

# SUMMARY

Inspired by embodied and enactive approaches to cognition, particularly the concept of social sensorimotor contingencies (see *Chapter 2* of this thesis), my doctoral research delivers a multi-level investigation of social interaction dynamics. To study the relationship between measures of interpersonal movement coordination and the experience of having an engaged social interaction, I designed two laboratory experiments that engage two participants in interactive coordination tasks: the BallGame and the Sonified MirrorGame. Both experimental paradigms employed quantitative as well as qualitative methods of observation to create detailed multi-level records of participants' interpersonal movement coordination and experience. While the BallGame presents a more goal-oriented task and investigates the influence of complementary versus shared information between participants, the Sonified MirrorGame compares free-form leader-follower as well as joint improvisation dynamics under distinct sensory feedback conditions.

In the BallGame (*Chapter 3*), participants took their seat in adjacent EEG laboratories, and used index finger movements to control the movement of a shared virtual ball, avoiding obstacle regions and collecting as many targets as possible in limited time. Of note: during half of the trials, the two players saw exactly the same six obstacles, and three remained invisible to both - the other half of the time, their view of the game environment was complementary, leaving no obstacle completely invisible. Informed about the two different joint play conditions, participants did not know, however, under which condition they were playing at any given moment. In the Sonified MirrorGame (*Chapter 4*), in turn, participants stood face to face at a table, each sliding a simple virtual avatar across the horizontal dimension of a tablet, so as to generate coordinated movements and interesting sounds together: when they moved apart, a rhythmic beat sound signalled the directed distance to their partner; when in close proximity, their movement generated orchestra sounds that reflected their speed and position along the line. Participants played the Sonified MirrorGame receiving audiovisual, visual or auditory feedback, as well as under the instruction to lead and follow, or jointly improvise.

In comprehensive analyses of both datasets, I demonstrated that post-trial experience ratings can be reliably predicted from parameters that capture participants' interpersonal movement coordination, gaming behaviour, personality differences, as well as the interaction context. In additional analyses of variance, I further highlighted changes in interpersonal movement coordination and social experience over time and across the different game conditions. Results from thematic content analyses that I performed of in-depth participant interviews further provided rich descriptions of their quality of attention and mode of play during the game. Overall, my findings suggest that a balance between interpersonal synchrony (predictability, success, similarity) and variability (surprise, challenge, difference) is central for social engagement. My results also point out concrete ways in which the interaction context influences social experience and interpersonal movement coordination: for example, the sensory feedback modality emerged as the most prominent predictor of experience in the Sonified MirrorGame, and interpersonal movement coordination in the BallGame was markedly enhanced by close

proximity to visible objects (targets and obstacles). Based on insights into aspects that were fun, frustrating or difficult, as well as specific moments of the interaction that participants experienced as meaningful or otherwise remarkable, I conducted elucidating follow-up analyses (BallGame) and identified central themes that provided an overview of my multi-level dataset and findings (both studies). As such, my work demonstrates the feasibility and effectiveness - if not necessity - of research that combines careful attention to participants' experience with multi-level quantitative observation and comprehensive modelling approaches, to elucidate the complex set of interrelated influences on interactive behaviour and experience.

Concepts from embodied and enactive cognition not only informed my experimental design, but turned into creative tools and practical implications for my everyday work as a researcher. In the epilogue, I present two extensive collaborative projects I engaged in to ground academic work in embodied and relational practices: the Playful Academic and the Mindful Researchers. What I learned from this applied work fits remarkably well with the conclusions I draw from my empirical investigations of engaged social interaction dynamics: sensitivity to relevant context, balances between self and other, and predictable and surprising elements, as well as the integration of differences across backgrounds of experience are key factors that determine the quality of participatory sense making - in study participants and interdisciplinary research teams alike. I therefore want my future work to actively involve participants and their living spaces as co-researchers: at eye's level with experts, each other and the research process.

# KURZFASSUNG

Die vorliegende Doktorarbeit befasst sich mit dem Zusammenhang zwischen interaktiver Bewegungsabstimmung und dem subjektiven Erleben einer bedeutsamen sozialen Interaktion. Um diesen Zusammenhang zu erforschen habe ich zwei Labor-Experimente entwickelt die jeweils zwei Probanden in ein interaktives Spiel verwickeln: das ‘BallGame’ und das ‘Sonified MirrorGame’. Meine Herangehensweise war dabei von Körper- und Handlungsorientierten Zweigen der Kognitionsforschung inspiriert: einem interdisziplinären Forschungsfeld das geistige Funktionen als unzertrennlich mit dem Körper und dessen lebenserhaltenden, dynamischen und wechselseitigen Beziehungen mit seinem physischen und sozialen Umfeld betrachtet. Insbesondere das Konzept der sozialen sensomotorischen Kontingenten (siehe Kapitel 2 dieser Arbeit) hat für meine Doktorarbeit eine entscheidende Rolle gespielt. Beide von mir umgesetzten Paradigmen verwenden sowohl quantitative als auch qualitative Beobachtungsmethoden, um detaillierte Aufzeichnungen über die zwischenmenschlichen Bewegungskoordination und das Erleben der Teilnehmer zu erstellen. Während das BallGame eine eher zielorientierte Aufgabe darstellt und den Einfluss von komplementären gegenüber geteilten Informationen zwischen den Teilnehmern untersucht, vergleicht das Sonified MirrorGame frei geformte Leader-Follower- sowie Improvisationsdynamiken unter unterschiedlichen sensorischen Feedback Bedingungen:

Teilnehmende des BallGames (Kapitel 3) nahmen in benachbarten EEG-Laboren Platz und steuerten mit Zeigefingerbewegungen einen gemeinsamen virtuellen Ball um Hindernisregionen herum und in Richtung so vieler Ziele wie möglich. Während der Hälfte der Versuchsdurchläufe sahen die beiden Spieler dabei genau die gleichen sechs Hindernisse, und drei blieben für beide unsichtbar - in der anderen Hälfte der Zeit war ihre Sicht auf die Spielumgebung komplementär, wobei kein Hindernis vollständig unsichtbar blieb. Obwohl über die beiden unterschiedlichen Spielbedingungen informiert, wussten die Teilnehmer nicht, unter welcher Bedingung sie gerade spielten. Beim Sonified MirrorGame (Kapitel 4) wiederum standen sich die Teilnehmer an einem Tisch gegenüber und steuerten jeweils einen einfachen virtuellen Avatar über die horizontale Dimension eines Tablets. Hier war die Aufgabe, gemeinsam koordinierte Bewegungen und interessante Klänge zu erzeugen: wenn die Probanden ihre Avatare auf der Linie voneinander entfernten, hat ein rhythmischer Beat die gerichtete Distanz zu ihrem Partner signalisiert; waren sie in unmittelbarer Nähe zueinander, erzeugten ihre Bewegungen Orchesterklänge die ihre Geschwindigkeit und Position entlang der Linie widerspiegelten. Die Teilnehmer spielten das Sonified MirrorGame unter audiovisuellem, visuellen oder auditiven Feedback, sowie unter der Anweisung zu führen und folgen, oder gemeinsam zu improvisieren.

In umfassenden Analysen beider Datensätze konnte ich daraufhin zeigen, dass sich die von den Probanden abgegebenen Erfahrungsbewertungen (nach jedem bzw. einigen wenigen Spieldurchläufen) zuverlässig aus Parametern vorhersagen lassen, die zwischenmenschliche Koordination, Spielverhalten, Persönlichkeitsunterschiede sowie den Interaktionskontext der Teilnehmer beschreiben. In Varianzanalysen konnte ich des weiteren Veränderungen in der zwischenmenschlichen Bewegungskoordination und der sozialen Erfahrung im Laufe der Zeit

sowie über die verschiedenen Spielbedingungen hervorheben. Die Ergebnisse aus thematischen Inhaltsanalysen von einzeln durchgeführten Interviews mit den Teilnehmern lieferten darüber hinaus differenzierte Beschreibungen der Aufmerksamkeitsqualität und Spielweise der Teilnehmer.

Insgesamt legen meine Ergebnisse nahe, dass ein Gleichgewicht zwischen zwischenmenschlicher Synchronität (Vorhersagbarkeit, Erfolg, Ähnlichkeit) und Variabilität (Überraschung, Herausforderung, Unterschiede) für soziale Involviertheit zentral ist. Meine Ergebnisse zeigen auch den konkreten Einfluss von Rahmenbedingungen auf das soziale Erleben sowie die zwischenmenschliche Bewegungskoordination. Beispielsweise hat sich die sensorische Feedback-Modalität als wichtigster Prädiktor für das Erleben im Sonified MirrorGame herausgestellt. Darüber hinaus konnten wir zeigen dass die zwischenmenschliche Bewegungskoordination im BallGame deutlich verbessert war wenn der Ball sich in unmittelbare Nähe zu sichtbaren Objekten befand (Zielen oder sichtbaren Hindernissen). Basierend auf den Ergebnissen der Interviews über lustige, frustrierende oder herausfordernde Aspekte des Spiels oder der Interaktion, sowie einzelne Begebenheiten, die von den Teilnehmern als bedeutsam oder anderweitig bemerkenswert empfunden wurden, führte ich aufschlussreiche Folgeanalysen (BallGame) durch und identifizierte zentrale Themen, die mir eine sinnvolle Übersicht über meinen Gesamtbefund ermöglichten (Sonified MirrorGame). Dadurch kann meine Arbeit zeigen, dass eine Kombination aus sorgfältiger Aufarbeit von Erfahrungsberichten, mit quantitativer Beobachtung auf mehreren Ebenen, sowie umfassenden Modellierungs-Ansätzen nicht nur möglich sondern äußerst effektiv - wenn nicht unabdingbar - ist, um dem komplexen Zusammenspiel aus Faktoren die soziales Engagement ausmachen, auf die Schliche zu kommen.

Körper- und Handlungsorientierten Zweige der Kognitionsforschung haben nicht nur maßgeblich mein experimentelles Design beeinflusst - sie wurden für mich zu kreativen Werkzeugen und haben meine tägliche Arbeit als Forscherin geprägt. Im Epilog stelle ich zwei umfangreiche Gemeinschaftsprojekte vor, an denen ich mich beteiligt habe um akademische Arbeit zu 'entsachlichen', und sie bewusst in unseren verkörperten und relationalen Praktiken zu verankern: der Playful Academic und die Mindful Researchers. Die Erkenntnisse die ich aus dieser angewandten Arbeit gezogen habe, passen erstaunlich gut zu den Schlussfolgerungen, die ich aus meinen empirischen Untersuchungen zur Dynamik engagierter sozialer Interaktionen gezogen habe: Sensibilität für den relevanten Kontext, eine Balance zwischen Selbst und Anderen - und vorhersehbaren und überraschenden Elementen - sowie die Integration diverser Erfahrungshintergründe sind wesentliche Faktoren, die die Qualität von Zusammenarbeit ausmachen - bei Studienteilnehmern, ebenso wie in interdisziplinären Forschungsteams. In meiner zukünftigen Arbeit möchte ich Teilnehmenden und ihren Lebensräumen deshalb auf Augenhöhe begegnen, und sie als Co-Forschende aktiv in die Gestaltung des Forschungsprozesses mit einbeziehen.

## Education

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| 2016 - 2022 | **PhD**<br>Department of Neurophysiology and Pathophysiology, UKE<br>supervised by Andreas K. Engel, Florian Göschl |
| 2013 - 2015 | **MSc**, Dual MSc Brain & Mind Sciences<br>École Normale Supérieure & Université Pierre et Marie Curie, Paris<br>Research project with Kevin O'Regan, Christoph Witzel, LPP<br>University College London<br>Research project with Raymond Dolan, Marcos Economides, ICN |
| 2010 - 2013 | **BA**, University College Maastricht<br>Exchange semester at Queens University, Kingston, Canada |

## Publications

**Lübbert A.** (2022) Curiosity - an emplaced virtue to move science towards the edge? Constructivist Foundations 17(3): 205–207. https://constructivist.info/17/3/205

Heimann K, Boelsbjerg HB, Allen C, van Beek M, Suhr C, **Lübbert A**, Petitmengin C (*in press*) The lived experience of remembering a "good" interview - Micro-phenomenology applied to itself. *Phenomenology and the Cognitive Sciences* (accepted, publ. Sept '22)

**Lübbert A**, Göschl F, Krause H, Schneider TR, Maye A & Engel AK (2021) Socializing Sensorimotor Contingencies. *Front. Hum. Neurosci.* 15:624610 https://doi.org/10.3389/fnhum.2021.624610

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Economides M, Kurth-Nelson Z, **Lübbert A**, Guitart-Masip M & Dolan RJ (2015) Model-Based Reasoning in Humans Becomes Automatic with Training. PLoS Comput Biol 11(9): e1004463. https://doi.org/10.1371/journal.pcbi.1004463

## EIDESSTATTLICHE VERSICHERUNG

Ich versichere ausdrücklich, dass ich die Arbeit selbständig und ohne fremde Hilfe verfasst, andere als die von mir angegebenen Quellen und Hilfsmittel nicht benutzt und die aus den benutzten Werken wörtlich oder inhaltlich entnommenen Stellen einzeln nach Ausgabe (Auflage und Jahr des Erscheinens), Band und Seite des benutzten Werkes kenntlich gemacht habe.

Ferner versichere ich, dass ich die Dissertation bisher nicht einem Fachvertreter an einer anderen Hochschule zur Überprüfung vorgelegt oder mich anderweitig um Zulassung zur Promotion beworben habe.

Ich erkläre mich einverstanden, dass meine Dissertation vom Dekanat der Medizinischen Fakultät mit einer gängigen Software zur Erkennung von Plagiaten überprüft werden kann.

Unterschrift:____________________________________