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Annäherungsmotivation: Eine Untersuchung ihrer neurophysiologischen Basis und zweier behavioraler Messinstrumente

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Abkürzungsverzeichnis

BAS	Behavioral Approach System
BIS	Behavioral Inhibition System
DA	Dopamin
dlPFC	Dorsolateraler Präfrontalcortex
EEG	Elektroenzephalogramm
EEfRT	Effort-Expenditure for Rewards Task
FAA	Frontale Alpha Asymmetrie
FFFS	Fight– Flight–Freeze System
GEE	Generalized Estimating Equation
HTC	Hard-Task-Choices
mA	Milliampere
MCLDA	Mesocorticolimbisches dopaminerges System
NAcc	Nucleus Accumbens
PET	Positronen-Emissions-Tomographie
RST	Reinforcement Sensitivity Theory
SHAM	tDCS ohne Stimulationseffekt (= Placebo)
tDCS	Transkranielle Gleichstromstimulation
TMS	Transkranielle Magnetfeldstimulation
V/m	Volt pro Meter (elektrische Feldstärke)

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Publikationen

Diese Dissertation basiert auf folgenden Artikeln, welche entweder bereits in Fachzeitschriften („peer-reviewed journals“) erschienen sind, oder dort zur Publikation eingereicht wurden.

Ohmann, H. A., Kuper, N., & Wacker, J. (2018). Left frontal anodal tDCS increases approach motivation depending on reward attributes. *Neuropsychologia, 119,* 417–423. https://doi.org/10.1016/j.neuropsychologia.2018.09.002

Ohmann, H. A., Kuper, N., & Wacker, J. (2020). A low dosage of the dopamine D2-receptor antagonist sulpiride affects effort allocation for reward regardless of trait extraversion. *Personality Neuroscience*, *3, E7*. https://doi.org/10.1017/pen.2020.7

Ohmann, H. A., Kuper, N., & Wacker, J. Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT). Submitted to *Journal of Research in Personality.*

"As she used to tell everybody, the magical ingredient in making an exceptionally successful life is what she called s*itzfleisch*. She meant sitting on your behind and putting in the huge effort needed to get the job done."

Walter Mischel

Zusammenfassung

Frühere Studien konnten zeigen, dass die menschliche Annäherungsmotivation korrelative Zusammenhänge sowohl zur frontalen Asymmetrie (relative Aktivität der linken im Vergleich zu den rechten Hirnregionen des Frontalhirns) als auch zur Dopamin(DA)-Konzentration insbesondere in den Arealen des mesocorticolimbischen dopaminegeren Systems (MCLDA) aufweist. Erstes Ziel meiner Dissertation war es, zu überprüfen, ob diese Zusammenhänge kausaler Natur sind. In Studie 1 habe ich dafür 60 gesunde Studierende an zwei Tagen untersucht und mittels tDCS (transkranielle Gleichstromstimulation) stimuliert. Anodale Stimulation mittels tDCS führte dabei im Vergleich zur SHAM-Stimulation (entspricht einem Placebo) zu einer erhöhten Bereitschaft für mehr physische Anstrengung innerhalb der eingesetzten Aufgabe (Effort-Expenditure for Rewards Task; EEfRT) – abhängig von den Eigenschaften der Belohnungen. Im Rahmen eines doppelblinden, experimentellen Designs in Studie 2 habe ich insgesamt 203 gesunde rechtshändige Männer untersucht, von denen die Hälfte 200mg Sulpirid und die andere Hälfte ein Placebo einnahmen und setzte eine modifizierte Variante der EEfRT ein, die den Einsatz von Strategien verhindern sollte. Die Ergebnisse widersprachen meiner Hypothese und deuten auf eine generell reduzierte Annäherungsmotivation nach Einnahme von Sulpirid hin. Insgesamt bestätigten aber beide Studien die neurophysiologische Basis der Annäherungsmotivation. Zweites Ziel meiner Dissertation war die Untersuchung der Reliabilität und Validität der beiden eingesetzten Varianten der EEfRT. In Studie 3 verglich ich daher zwei Varianten der EEfRT innerhalb eines experimentellen Designs (N = 120). Die Ergebnisse waren durchmischt, denn während die Reliabilität beider Varianten zufriedenstellend war und die grundsätzliche Validität der Belohnungseigenschaften mit bisherigen Befunden übereinstimmten, zeigten sich nur vereinzelte Zusammenhänge zur Persönlichkeit. In Studie 4 habe ich die Originalversion der EEfRT erneut hinsichtlich ihrer Reliabilität und Validität in einer größeren Stichprobe (N = 394) untersucht, um die statistische Power zur Entdeckung auch kleinerer Zusammenhänge zu

erhöhen. Überraschenderweise konnte keiner der zuvor beobachteten Zusammenhänge mit der Persönlichkeit bestätigt werden. Dies steht in Einklang mit der häufig berichteten eingeschränkten Vergleichbarkeit zwischen selbstberichteter Persönlichkeit und experimentell erfasstem Verhalten. Zusammenfassend konnten die in meiner Dissertation durchgeführten Studien die neurophysiologische Basis der Annäherungsmotivation grundsätzlich bestätigen. Während die Reliabilität der beiden eingesetzten Varianten der EEfRT zufriedenstellend war, konnte deren Validität allerdings nur sehr eingeschränkt bestätigt werden. Die Implikationen der Ergebnisse werden in der vorliegenden Dissertation ebenso diskutiert, wie methodische Überlegungen für zukünftige Studien.

1. Einleitung

1.1 Annäherung und Vermeidung

1.1.1 Theorie und Messverfahren

Motivationsprozesse beeinflussen unser Verhalten maßgeblich, indem sie Stimuli als für uns potentiell belohnend oder schädlich einstufen (Lazarus, 1991a, 1991b). Diese Bewertung führt dazu, dass wir uns einem Stimulus nähern, oder diesen Stimulus vermeiden. Dieses Konzept lässt sich auf nahezu das gesamte menschliche Handeln übertragen, sei es bei der Entscheidung für oder gegen den morgendlichen Einkauf beim Bäcker (verbunden mit der Mühe aus dem Haus zu gehen, aber auch verbunden mit dem belohnenden Geschmack der Brötchen), oder sei es bei der Entscheidung darüber, eine Doktorarbeit zu schreiben (verbunden mit jahrelanger mühevoller Arbeit, aber auch verbunden mit der potentiellen Belohnung eines Doktortitels). Menschen unterscheiden sich jedoch grundsätzlich in ihrer Bewertung verschiedener Stimuli und es wird angenommen, dass unsere Persönlichkeit einen maßgeblichen Anteil an dieser Unterschiedlichkeit hat. Gray (1990) stellte hierzu eine bis heute einflussreiche Theorie der Persönlichkeit auf, welche er in der „Reinforcment Sensitivity Theory“ (Gray, 1990) zusammenfasste. Grundannahme der Theorie ist es, dass unsere Bewertung von Stimuli und damit unser Handeln von drei verschiedenen Motivationssystemen geleitet wird. Das erste Motivationssystem ist das „Behavioral Activation System“ (BAS). Dieses aktiviert Annäherungsverhalten, welches uns Zugang zu Stimuli mit potentiell belohnenden Konsequenzen ermöglichen soll. Dem gegenüber steht das zweite Motivationssystem, das „Behavioral Inhibition System“ (BIS), welches Verhalten verhindert / unterbricht, welches uns Stimuli mit potentiell schädlichen Konsequenzen aussetzen würde. Das dritte System, welches in dieser Dissertation nicht weiter behandelt werden soll, ist das so genannte „Fight-Flight-Freeze-System“ (FFFS). Wie der Name vermuten lässt, handelt es sich um ein System, welches uns vor potentiell lebensbedrohlichen Gefahren schützen soll und dessen Reaktionen (kämpfen, flüchten, erstarren) als Notfallreaktionen verstanden werden können. Corr (2001) betont, dass

die beiden ersten Systeme (BAS, BIS) interaktionistisch wirken. Bei der Bewertung eines Stimulus nehmen beide Systeme die jeweils relevanten Hinweisreize auf (BAS: belohnende Reize; BIS; schädliche Reize) und nach der Abwägung dieser Reize kommt es entweder zu einer Annäherung oder einer Vermeidung. Da es sich bei diesem Modell um ein Persönlichkeitsmodell handelt und somit zeitlich stabile interindividuelle Unterschiede angenommen werden können, wurden schon nach kurzer Zeit Fragebogen erstellt, welche diese Dispositionen erfassen sollen. Allen voran seien hier die BIS/BAS–Skalen (Carver & White, 1994; Strobel et al., 2001) genannt, welche die Sensitivität für Belohnungen und Bestrafungen als Disposition zu erfassen versuchen. Mittlerweile existieren zahlreiche andere Fragebogenverfahren, welche sich teils auch differenzierter mit der Wahrnehmung der Belohnungen als solche auseinandersetzen. So unterscheidet die „Temporal Experience of Pleasure Scale" (TEPS; Gard et al., 2006) zwischen dem antizipatorischen Genuss im Sinne der Erwartung einer Belohnung und dem konsumatorischen Genuss im Sinne der Erfahrung einer Belohnung. Auch andere Persönlichkeitseigenschaften, wie z. B. Extraversion zeigen eine inhaltliche Nähe zur Annäherungsmotivation und werden in diesem Zusammenhang häufig untersucht (Smillie, 2013).

Rufen wir uns an dieser Stelle kurz die oben genannten Beispiele in Erinnerung (Besuch beim Bäcker, Verfassen einer Doktorarbeit), so wird deutlich, dass die meisten Stimuli in unserem Alltag nicht ausschließlich positive oder ausschließlich negative Aspekte beinhalten und eine Abwägung der verschiedenen Konsequenzen von entscheidender Bedeutung ist. Diese sogenannte „Kosten-Nutzen-Analyse" (Phillips et al., 2007) berücksichtigt dabei alle für uns relevanten Aspekte, wie die Belohnungshöhe (Depue & Collins, 1999), oder den zeitlichen Aufwand und die Wahrscheinlichkeit, auch wirklich belohnt zu werden (Chong et al., 2015; Hauber & Sommer, 2009). Diesen Annahmen folgend erscheint die Erfassung auf Verhaltensebene im Rahmen der „Reinforcement Sensitivity Theory" (Gray, 1990) fast schon zwingend; lassen sich doch mit ihr sehr konkrete Annahmen über das zu erwartende Verhalten

aufstellen. So sind im Laufe der Zeit diverse Tests entstanden, welche es ermöglichen sollen, die Annäherungsmotivation bzw. die Vermeidungsmotivation einer Person zu erfassen. Viele dieser Tests basieren auf einem „Effort Discounting Modell“, welches grundsätzlich misst, wie viel Anstrengung eine Person bereit ist zu erbringen, um eine potentielle Belohnung in einer bestimmten Höhe zu erlangen (Hartmann, Hager & Reimann et al., 2015; Hartmann, Hager, Tobler et al., 2013; Klein-Flugge et al., 2015). Dabei werden die Anstrengungen und die Belohnungen gezielt variiert. Die Anstrengungen umfassen dabei in der Regel körperliche Anstrengungen, wie das Pressen eines Griffs (Clery-Melin et al., 2011; Kurniawan et al., 2010; Reddy et al., 2015), oder das Drücken von Tasten oder Hebeln (Hershenberg et al., 2016; Lane et al., 2005; Strauss et al., 2016). Nicht von ungefähr wecken diese Aufgaben Erinnerungen an bekannte Aufgaben aus der Tierforschung. Viele dieser Aufgaben basieren auf Tiermodellen und wurden post-hoc zur Erfassung der menschlichen Motivation umgewandelt (Vergleich z. B.: Salamone et al., 1994). Auch in meiner Dissertation habe ich eine solche Aufgabe eingesetzt, die so genannte „Effort-Expenditure for Rewards Task (EEfRT; Treadway et al., 2009). Diese Aufgabe, welche ich in allen Studien meiner Dissertation eingesetzt habe, wird unter Punkt 1.3 genauer vorgestellt. Im Wesentlichen verlangt die Aufgabe von den Versuchspersonen, Entscheidungen über den Einsatz verschieden intensiver körperlicher Anstrengungen (wiederholtes Drücken einer Taste) für verschieden große Belohnungen (Geld) zu treffen. Es werden Anstrengungen und Belohnungen variiert und die Bereitschaft zur körperlichen Anstrengung als Maß der Annäherungsmotivation herangezogen.

1.1.2 Neuronale Korrelate

Grays „Reinforcement Sensitivity Theory“ (1990) geht explizit von einer neurophysiologischen Verankerung der postulierten Motivationsprozesse aus und deren tatsächliche Existenz wurde entsprechend auch bereits vielfach untersucht. Im Folgenden möchte ich nur auf zwei potentielle neurophysiologische Korrelate eingehen, welche für meine Dissertation besonders relevant sind, (a) die frontale Asymmetrie und (b) das mesocorticolimbische dopaminerge System (MCLDA).

(a) Frontale Asymmetrie

Einer der am häufigsten untersuchten neurophysiologischen Marker der BIS/BAS–Systeme ist die frontale Asymmetrie. Die Theorien zur frontalen Asymmetrie basieren auf der Annahme, dass die frontalen Hirnregionen in Abhängigkeit der Motivationslage und der Emotionserfahrung asymmetrisch aktiviert sind (Harmon-Jones & Gable, 2018; Rutherford & Lindell, 2011). Die ursprüngliche Annahme, dass eine stärker linksseitige frontale Aktivierung positivere Emotionen und eine stärker rechtsseitige frontale Aktivierung negative Emotionen wiederspiegeln, die frontale Asymmetrie also abhängig von der „Valenz“ der Emotion ist (Tomarken et al., 1992), gilt derweil als überholt. Stattdessen geht man davon aus, dass eine stärker linksseitige frontale Aktivität mit einer größeren Annäherungsmotivation (BAS) und eine stärker rechtsseitige frontale Aktivität mit einer stärkeren Vermeidungsmotivation (BIS) assoziiert sind – unabhängig von der Valenz (Harmon-Jones & Gable, 2018; Rutherford & Lindell, 2011). Die Theorie erklärt damit auch, warum z. B. Ärger als eine eindeutig negative Emotion mit einer stärkeren linksfrontalen Aktivität einhergeht (Harmon-Jones, 2007; Hewig et al., 2004), insofern es sich bei dieser Emotion auch um Annäherungsmotivation handelt. Ein Zusammenhang zwischen den weiter oben vorgestellten BIS/BAS–Skalen (Carver & White, 1994; Strobel, Beauducel, Debener, & Brocke, 2001) und der frontalen Asymmetrie konnten Sutton und Davidson (1997) bereits vor über 20 Jahren nachweisen. Nachdem Sie einen Differenzwert beider Skalen berechneten, konnten Sie zeigen, dass Personen mit höherer

Ausprägung in der BAS-Skala eine stärker linksfrontale Aktivierung und Personen mit einer höheren Ausprägung in der BIS-Skala eine stärker rechtsfrontale Hirnaktivierung zeigten. Die Hirnaktivität wurde dabei mittels eines Elektroenzephalogramms (EEG) gemessen. Bei der Messung der frontalen Asymmetrie wird häufig die Aktivität des Alphabands im Ruhezustand (8 – 13 Hz; Ruhe–EEG) untersucht, wobei stärkere Alphawellen für eine geringere Hirnaktivität sprechen, weswegen man auch von der frontalen Alpha Asymmetrie spricht (FAA; Coan & Allen, 2004; Davidson, 1988). Jedoch ist die Messung im Ruhe–EEG mittlerweile sehr umstritten, da diese nicht frei von Kontextinformationen ist, die auch Annäherungsmotivation auslösen können. So zeigten z. B. Männer während des Ruhe–EEGs eine stärker linksfrontale Hirnaktivität, wenn sie von Frauen untersucht wurden (Wacker et al., 2013). Außerdem wurde der Zusammenhang zwischen Persönlichkeitseigenschaften und der frontalen Hirnaktivität im Ruhe-EEG in einer aktuellen Meta-Analyse, in der allenfalls nur sehr kleine Zusammenhänge gefunden wurden, grundsätzlich in Frage gestellt (Kuper et al., 2019). Insofern erscheinen Studien, welche die frontale Asymmetrie während der Bearbeitung einer Aufgabe erfassen und in denen somit auch ein konkreter Belohnungs- oder Vermeidungskontext vorliegt, deutlich vielversprechender. So konnten z. B. Schöne et al. (2016) eine stärker linksfrontale Hirnaktivität während der Präsentation emotional salienter Stimuli evozieren.

(b) Mesocorticolimbisches dopaminerges System

Einen zweiten neurophysiologischen Marker der BIS/BAS–Systeme stellt das mesocorticolimbische dopaminerge System (MCLDA) dar. Das MCLDA ist ein weitverzweigtes neuronales Netzwerk, welches verschiedene Hirnregionen, vom ventralen Tegmentum über den anterioren Cingulus bis hin zum präfrontalen Cortex miteinander verbindet (Brooks & Berns, 2013; Hickey et al., 2010; siehe Abbildung 1) und wesentlich für die Verarbeitung von Belohnungen zuständig ist. Zentraler Neurotransmitter innerhalb dieses neuronalen Netzwerkes ist Dopamin (DA). DA wird in vielerlei Hinsicht mit der Verarbeitung von Belohnungen assoziiert (Berridge & Kringelbach, 2008; Salamone et al., 2006), so wurde

u.a. ein Zusammenhang zwischen der DA-Aktivität und der Verarbeitung der Belohnungshöhe nachgewiesen (Bromberg-Martin et al., 2010). Dabei bewirkt die Bindung von DA an den Rezeptoren (es existieren 5 Typen: D1 bis D5) der Nervenzelle unterschiedliche neuronale Reaktionen. So verursacht die Bindung von DA an den Rezeptortypen D1 und D5 einen exzitatorischen Effekt und die Bindung an den Rezeptortypen D2, D3 und D4 einen inhibitorischen Effekt (Serra et al., 1990). Jedoch ist auch die Position der Rezeptoren zu beachten, da präsynaptische und postsynaptische Rezeptoren unterschiedliche Effekt auf die Signalübertragung haben können (Missale et al., 1998; Serra et al., 1990).

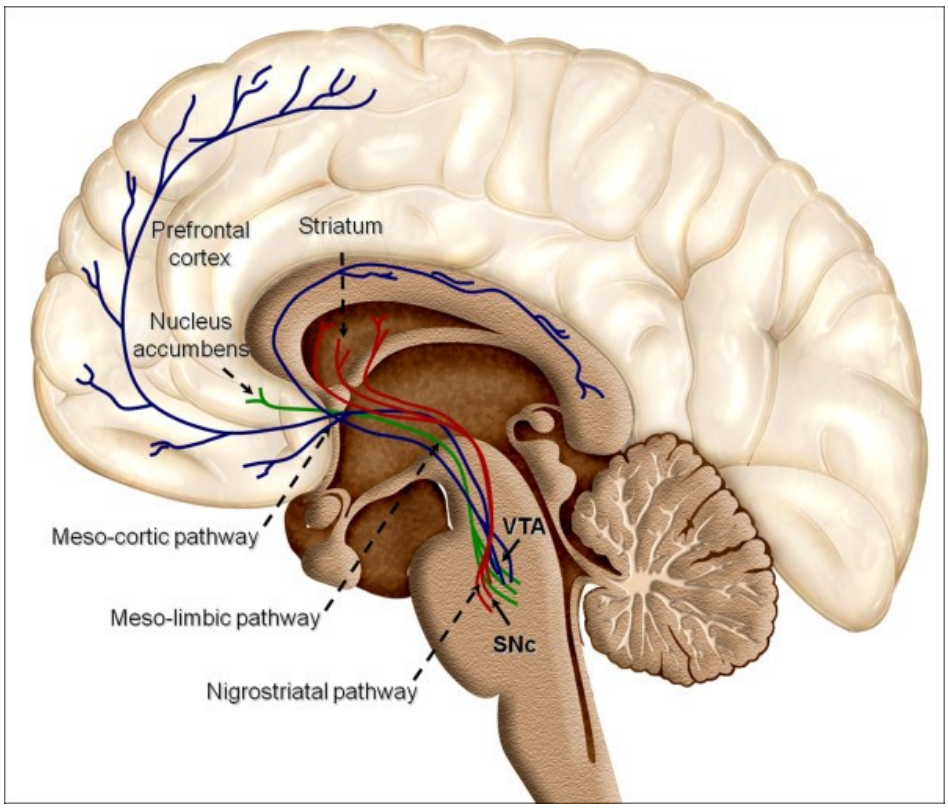

Abbildung 1. Das mesocorticolimbische dopaminerge System (MCLDA). SNc: Substantia Nigra pars compacta; VTA: Ventrales Tegmentum (Aus: Arias-Carrián et al., 2010, Seite 2).

Allgemein fördert DA zielgerichtetes Verhalten (Depue & Collins, 1999), ist mit motivationalen Aspekten assoziiert (Berridge & Kringelbach, 2008; Salamone et al., 2006) und erhöht die Wahrscheinlichkeit von Verhaltensweisen, die mit der größtmöglichen Belohnung assoziiert sind (Nicola et al. 2004; Treadway & Zald, 2011; Walton et al., 2006). Die Annahme, dass die DA-Konzentration im MCLDA somit auch die zuvor erwähnte „Kosten-Nutzen-Analyse“ beeinflusst (Philips et al., 2007), konnte im Tiermodell bereits bestätigt werden (Salamone et al., 2018). Auch wurden Zusammenhänge zwischen der Anzahl der DA-Rezeptoren und den selbstberichteten Ausprägungen in den BIS/BAS–Skalen nachgewiesen (Tomer et a., 2014). Insgesamt sprechen die Befunde für die Bedeutung DAs im Kontext der Annäherungsmotivation und für eine neurophysiologische Verankerung dieser. Jedoch kann aus den überwiegend korrelativen Studien keine kausale Schlussfolgerung gezogen werden. Daher möchte ich im folgenden Kapitel auf Methoden zur neurophysiologischen Manipulation eingehen.

1.2 Neurophysiologische Manipulation

1.2.1 tDCS

1.2.1.1 Physiologische Effekte

Bei der transkraniellen Gleichstromstimulation (transcranial direct current stimulation; tDCS) werden die unter den Elektroden liegenden Hirnareale durch einen schwachen elektrischen Strom stimuliert. Dabei ist die Stimulation so schwach, dass sie auf Ebene der Neurone keine Aktionspotentiale und somit keine direkt sichtbaren Effekte auslösen kann, ganz im Gegensatz zur transkraniellen Magnetfeldstimulation (TMS; >100 V/m bei TMS im Vergleich zu <1V/m bei tDCS). Die Stimulation verändert stattdessen die Polarisierung der stimulierten Neurone und verändert somit deren Erregbarkeit (Bikson et al., 2012).

Dabei wird angenommen, dass die Anode und die Kathode (es werden üblicherweise nur zwei Elektroden verwendet) die neuronale Erregbarkeit in unterschiedlicher Richtung beeinflussen. Die Stimulation mittels Anode depolarisiert demnach die kortikalen Neurone, was wiederrum den benötigten dendritischen Input verringert und somit zu einer höheren neuronalen Erregbarkeit führt. Demgegenüber hyperpolarisiert die Stimulation mittels Kathode die kortikalen Neurone, erhöht damit den benötigten dendritischen Input und verringert demnach die neuronale Erregbarkeit (Paulus et al., 2012). Die Wirkweise von tDCS wird daher in der Literatur auch als „Priming“ beschrieben (Miniussi & Ruzzoli, 2013). Neben verschiedenen technischen Aspekten (mehr dazu unter 1.2.1.2) werden die Effekte weiterhin in “Online” und “Offline” unterschieden. “Online” bedeutet in diesem Fall, dass die Effekte während der Stimulation auftreten und “Offline”, dass die Effekte nach der Stimulation auftreten. Vielfältige Studien konnten langanhaltende Effekte der Stimulation mittels tDCS über Minuten bis hin zu einigen Stunden nachweisen (Sela & Lavidor, 2014). Jedoch weisen andere Studien daraufhin, dass bestimmte Effekte nur “Online”, also während der Stimulation, auftreten (z. B. Hone-Blancet et al., 2015). Insofern sollte idealerweise stets zwischen diesen beiden Effekttypen unterschieden werden. Außerdem gilt es bei tDCS zu beachten, dass die Effekte der Stimulation noch nicht vollständig ergründet sind und nicht nur am Ort der Stimulation auftreten können,

sondern auch weiterverstreut über das Gehirn nachweisbar sind (Wörsching et al., 2016). In diesem Zusammenhang ist ein weiterer beachtenswerter Aspekt, die mögliche Interaktion der Stimulationseffekte mit der durch eine bestimmte Aufgabe hervorgerufenen Hirnaktivität (Bortoletto et al., 2015).

1.2.1.2 Technische Parameter

In den meisten Studien, die tDCS einsetzen, ist die Untersuchung der Wirkung einer bestimmten Platzierung der Elektroden bzw. ein Vergleich zweier Stimulationstypen (anodale Stimulation / kathodale Stimulation), oder der Vergleich zu einer SHAM-Stimulation von zentraler Bedeutung. Die sogenannte SHAM-Stimulation stellt dabei ein Placebo dar, da sie keinen Stimulationseffekt verursacht, jedoch durch Anbringung der Elektroden und einer minimalen Stimulationsdauer (in der Regel ca. 30s) eine echte Stimulation vortäuscht (Fonteneau et al., 2019). Neben der unter 1.2.1.1 beschriebenen Unterschiedlichkeit der physiologischen Effekte bei der Stimulation mittels tDCS, darunter der Zeitpunkt der Effekte (Online/Offline) und die Interaktion mit der durch eine Aufgabe evozierten Hirnaktivität, müssen auch verschiedene technische Aspekte beachtet werden. So können z. B. unterschiedliche Stimulationsdauern nachweislich unterschiedlich lange „Offline"–Effekte bewirken, wobei sehr lange Stimulationen von über 120 Minuten die ursprüngliche Wirkung umkehren können (Paulus et al., 2012). Zudem sind die Größe der Elektroden (üblicherweise 35cm^2: Paulus et al., 2012) und die Stimulationsstärke zu beachten. Letztere variiert in der Forschung üblicherweise zwischen 1mA (z. B. Miller et al., 2015), 1,5mA (z. B. Riva et al., 2015) und 2mA (z. B. Kesser et al., 2011; Vanderhasselt et al., 2013). In der Forschung existieren keine standardisierten Vorgaben darüber, welche Parameter bei welcher Fragestellung eingesetzt werden sollten. Dies macht eine genaue Lektüre der relevanten Studien und die Anpassung der Parameter umso wichtiger.

1.2.1.3 Manipulation der Annäherungsmotivation

Um die Annäherungsmotivation mittels tDCS manipulieren zu können, muss zunächst ein geeignetes Setting, welches die unter Punkt 1.2.1.1 und 1.2.1.2 genannten Aspekte berücksichtigt, gefunden werden. In bisherigen tDCS–Studien wurden zur Manipulation der Annäherungsmotivation dabei häufig versucht, die weiter oben beschriebene frontale Asymmetrie zu beeinflussen.

Dabei fanden sich jedoch bisher sehr gemischte Ergebnisse. Während einige Studien die Modellannahmen der frontalen Asymmetrie bestätigten (Chrysikou et al., 2016; Hortensius et al., 2012; Kelley, Hortensius & Harmon-Jones, 2013; Kelley, Eastwick, Harmon-Jones et al., 2015; Riva et al., 2015), sprachen die Ergebnisse anderer Studien dagegen (Fecteau et al., 2007; Russo et al., 2017; Shen et al., 2016; Soutschek et al., 2018; Ye et al., 2015). Zumindest teilweise dürften die unterschiedlichen Ergebnisse in den sehr unterschiedlichen technischen und experimentellen Settings begründet sein. Neben den Variationsmöglichkeiten auf Seiten der Stimulation mittels tDCS unterscheiden sich dabei auch die eingesetzten Testverfahren, welche die Annäherungsmotivation sehr unterschiedlich operationalisierten. So umfassen die Operationalisierungen z. B. Reaktionen in sozialen Situationen (Hortensius et al., 2012), Risikobereitschaft (Russo et al., 2017) und Anstrengungsbereitschaft (Soutschek et al., 2018). Somit bleibt der kausale Zusammenhang zwischen frontaler Asymmetrie und Annäherungsmotivation bisher ungeklärt (Kelley et al., 2017). Nach Sichtung der relevanten Literatur lässt sich dennoch festhalten, dass die meisten Studien versuchen, die frontale Asymmetrie mit der in der Abbildung 2 dargestellten Anordnung zu manipulieren. Dabei wird die Anode über dem linken dorsolateralen Präfrontalcortex (dlPFC) angebracht. Die Position der Anode wird dabei in der Regel mittels EEG–Kappe bestimmt und entspricht dabei der F3-Position (10–20 System), die Kathode wird in der Regel über dem rechten supraorbitalen Areal angebracht (De Witte et al., 2018). Hiermit soll einerseits eine höhere Spannung auf Grund der geringen Entfernung beider Elektroden zueinander und anderseits ein möglichst geringer

Stimulationseffekt der Kathode auf Grund der hohen Schädeldicke an dieser Position erreicht werden (Faria et al., 2011). Studien, welche das Entscheidungsverhalten der Teilnehmer beeinflussen wollten, haben jedoch auch bereits andere Settings erfolgreich angewandt und z. B. die Anode über dem rechten dlPFC angebracht (Bogdanov et al., 2017).

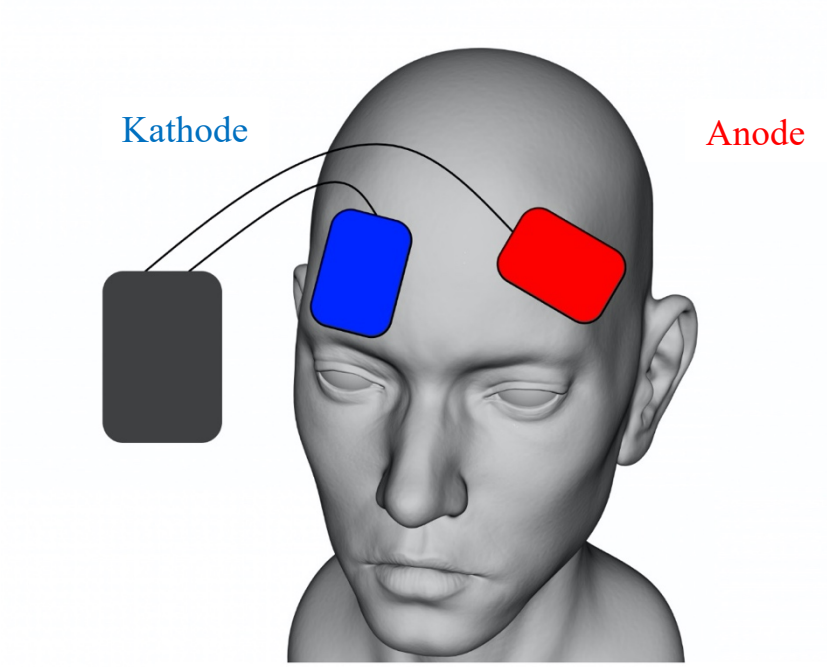

Abbildung 2. Schematische Darstellung der Stimulation mittels tDCS zur Manipulation der frontalen Asymmetrie. Die Anode (rot) wird dabei über dem dorsolateralen Präfrontalcortex (dlPFC) und die Kathode (blau) über dem rechten supraorbitalen Areal angebracht (eigene Darstellung).

1.2.2 Sulpirid

1.2.2.1 Physiologische Effekte

Sulpirid ist ein selektiver D2-Rezeptor-Blocker (Ruther et al., 1999). Das bedeutet, dass Sulpirid nur an speziellen Rezeptoren (den D2-Rezeptoren) andockt und diese blockiert. D2-Rezeptoren können in verschiedenen Arealen des Gehirns gefunden werden, jedoch sind sie am häufigsten in mesolimbischen Strukturen, wie dem Striatum oder dem Nucleus Accumbens (NAcc), anzutreffen (Missale et al., 1998; Beaulieu et al., 2011). Entsprechend wird angenommen, dass die Einnahme von Sulpirid das unter 1.1.2 beschriebene MCLDA

beeinflusst. Sulpirid wird zur Behandlung verschiedener Krankheiten eingesetzt, wobei dessen Dosierung von zentraler Bedeutung ist. Es wird angenommen, dass niedrigere Dosierungen dazu führen, dass insbesondere präsynaptische D2-Rezeptoren blockiert werden und dies zu einer erhöhten DA-Konzentration im synaptischen Spalt und damit zu einer Erhöhung der Signalübertragung führt (Tagliamonte et al., 1975; Rankin et al., 2009). Demgegenüber wird angenommen, dass höhere Dosierungen dazu führen, dass insbesondere postsynaptische D2-Rezeptoren blockiert werden, was zu einer Verringerung der DA-Konzentration im synaptischen Spalt und damit zu einer Verringerung der Signalübertragung führt (Eisenegger et al., 2014; Boschen et al., 2015). Daher werden niedrigere Dosierungen, welche durch die höhere DA–Konzentration die Annäherungsmotivation steigern sollten, z. B. zur Behandlung von Depressionen eingesetzt (Serra et al., 1990; Kuroki et al., 1999). Während höhere Dosierungen, die durch die geringere DA-Konzentration die Annäherungsmotivation senken sollen, zur Behandlung von Schizophrenien verwendet werden (Miyamoto et al., 2005; Lai et al., 2012). Beachtenswert ist dabei, dass die genannten Effekte nicht grundsätzlich unabhängig auftreten, sondern z. B. in Abhängigkeit der Zeit zwischen der Einnahme und der Testung zu unterschiedlichen Zeitpunkten auftreten können (Mueller et al., 2011). Zudem ist zu beachten, dass auch die Persönlichkeit (insbesondere: Extraversion) einen Einfluss auf die Wirkung von Sulpirid haben kann. Extraversion beeinflusst die Verarbeitung von Belohnungen (Smillie, 2013) und wird auch mit der individuellen DA–Aktivität assoziiert (Depue & Collins, 1999; Wacker & Smillie, 2015). So konnten einige Studien bereits einen moderierenden Effekt der Extraversion auf die Wirkung Sulpirids nachweisen, wobei die Extraversion den Effekt Sulpirids auf verschiedene neurophysiologische Marker und Verhaltensmessungen vollständig umkehrte (Chavanon et al., 2013; Mueller et al., 2014; Wacker et al., 2013; Wacker, 2018).

1.2.2.2 Manipulation der Annäherungsmotivation

Es liegen nur wenige Studien vor, die den Einfluss von Sulpirid auf das MCLDA und die Annäherungsmotivation im Belohnungskontext untersucht haben. Dabei muss zunächst wieder auf die methodische Vielfalt der Studien hingewiesen werden. Insbesondere die Dosierung Sulpirids wird dabei in den Studien sehr unterschiedlich gehandhabt und reicht von 400 bis 800 mg. Außerdem wird gelegentlich auch Amisulpirid eingesetzt (z. B. Kahnt et al., 2015), welches sich in seiner Wirkweise jedoch nicht von Sulpirid unterscheiden soll. Damit handelt es sich um vergleichsweise hohe Konzentrationen, die nach den unter 1.2.2.1 genannten Aspekten zu einer verringerten Annäherungsmotivation führen sollten. Während einige Studien eine verringerte Annäherungsmotivation auf Grund der Einnahme von Sulpirid nachweisen konnten, wie z. B. eine verringerte Bereitschaft zeitlich nahe Belohnungen auszuwählen (Weber et al., 2016), in Entscheidungssituationen geringen Gewinnwahrscheinlichkeiten weniger Beachtung geschenkt wurde (Ojala et al., 2018), oder auch die Fähigkeit, Belohnungen korrekt vorherzusagen, beeinträchtigt war (Diederen et al., 2017), haben andere Autoren keinerlei Effekte nachweisen können (Kahnt et al., 2015). Eine beachtenswerte Studie von Eisenegger et al. (2014) verglich die Effekte verschiedener Sulpirid-Konzentrationen in einer Lernaufgabe mit Belohnungskontext, wobei höhere Dosierungen die Lernfähigkeit stärker verringerten. Dabei wurden die tatsächlichen Dosierungen ebenfalls durch Blutproben überprüft und somit gegenüber anderen Einflussfaktoren abgesichert. Die Ergebnisse sprechen insgesamt für einen inhibierenden Effekt höherer Sulpirid-Dosierungen in Belohnungskontexten. Die Wirkung geringer Dosierungen im Belohnungskontext hingegen erscheint nach meiner Recherche bisher noch kaum erforscht. Die vorliegenden Studien, welche keinen expliziten Belohnungskotentext untersuchten, weisen auf eine Steigerung der Annäherungsmotivation hin, welche jedoch wie weiter oben beschrieben durch den situativen Kontext und durch die Persönlichkeit moduliert werden können (z. B. Chavanon et al., 2013).

1.3 Die Effort-Expenditure for Rewards Task (EEfRT)

1.3.1 Aufgabendesign

Da die EEfRT (Treadway et al., 2009) wie unter Abschnitt 1.1.1 beschrieben für meine Dissertation von zentraler Bedeutung war und in allen Studien zum Einsatz kam, möchte ich die Aufgabe bereits an dieser Stelle ausführlicher vorstellen und insbesondere auf Vorbefunde zu ihrer Reliabilität und Validität eingehen. Die EEfRT basiert auf einem aus dem Tiermodell übertragenen Aufgabendesign (Salamone et al., 1994), dessen zentrale Messgröße die wiederholte Entscheidung zwischen zwei Handlungsalternativen darstellt. Die beiden Handlungsalternativen (leichte Aufgabe VS schwere Aufgabe) unterscheiden sich in der Höhe der benötigten physischen Anstrengung und der Höhe der potentiellen Belohnungen. Wie man in Abbildung 3 sehen kann, umfasst die „physische Anstrengung“ dabei das wiederholte Drücken der Leertaste, wobei diese für die leichte Aufgabe innerhalb von 7 Sekunden 30 mal mit dem Zeigefinger gedrückt werden muss und für die schwere Aufgabe innerhalb von 21 Sekunden 100 mal mit dem kleinen Finger gedruckt werden muss. Um nun die Anstrengungsbereitschaft nach dem eingangs erwähnten „effort discounting model“ (Hartmann et al., 2015) genauer untersuchen zu können, wird der Gewinnbetrag für die schwere Aufgabe (1.21€ bis 4.30€) und auch die Gewinnwahrscheinlichkeit (12% / 50% / 88%) variiert. Zentrale abhängige Variable ist dabei die relative Häufigkeit der Entscheidung für die schwere Aufgabe („Hard-Task-Choices“; HTC) Unabhängig von den Entscheidungen in den einzelnen Trials ändert sich die Gesamtdauer der Aufgabe nicht. Wie sich im Laufe meiner Dissertation herausstellte, ist die originale EEfRT dadurch jedoch mit der Gefahr verbunden, strategisches Denken zu erfassen. Daher sei an dieser Stelle auch bereits meine modifizierte Variante der EEfRT vorgestellt, welche die ursprüngliche Entscheidungsmöglichkeit entfernt, und stattdessen die Belohnung pro Klick (1/ 2/ 3/ 4/ 5 Cent) variiert, während die Gewinnwahrscheinlichkeit identisch zur originalen EEfRT variiert wird und jeder Durchgang nun immer genau 20 Sekunden dauert (siehe Abbildung 4).

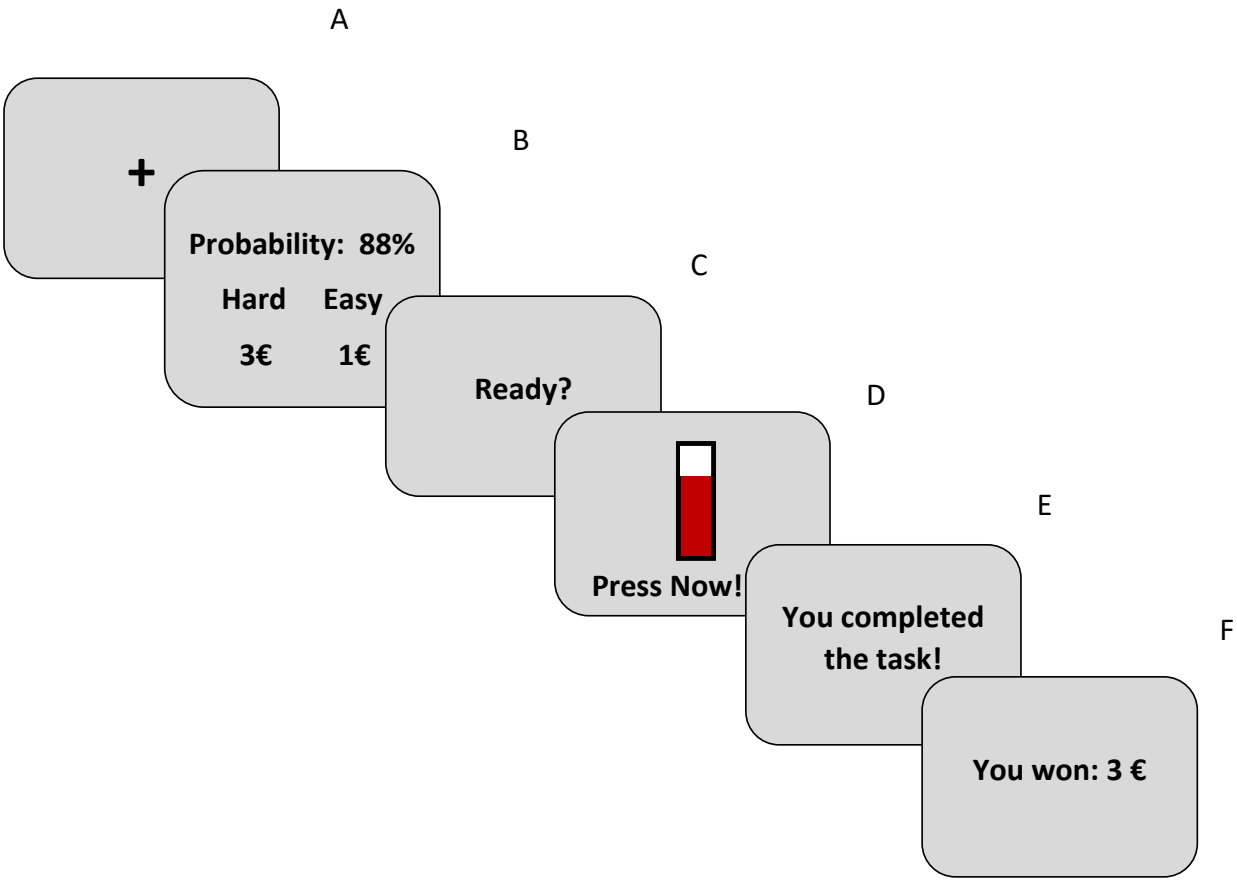

Abbildung 3. Schematische Darstellung eines Trials der originalen EEfRT. Zunächst erscheint ein Fixationskreuz für eine Sekunde (A). Dieses wird von einem Wahlbildschirm gefolgt, auf welchem die Teilnehmer 5 Sekunden Zeit haben, um sich zwischen der leichten Aufgabe oder der schweren Aufgabe zu entscheiden. Hierbei werden die möglichen Gewinnbeträge und die Gewinnwahrscheinlichkeit angezeigt (B). Sollte ein Teilnehmer keine Entscheidung treffen, wird zufällig eine der beiden Aufgaben präsentiert. Nach kurzer Präsentation eines Bildschirms zur Bereitmachung vor der Aufgabe (C, 1 Sekunde), erscheint die zentrale Aufgabe (D). Durch das Drücken der Leertaste wird der angezeigte Balken zunehmend mit roter Farbe aufgefüllt, bis die Aufgabe erfüllt ist oder die Zeit abgelaufen ist. Anschließend wir das Ende der Aufgabe inklusive Rückmeldung über den Erfolg/Misserfolg signalisiert (E, 2 Sekunden) und ein Feedback über den gewonnenen Geldbetrag (F, 2 Sekunden) eingeblendet (eigene Darstellung).

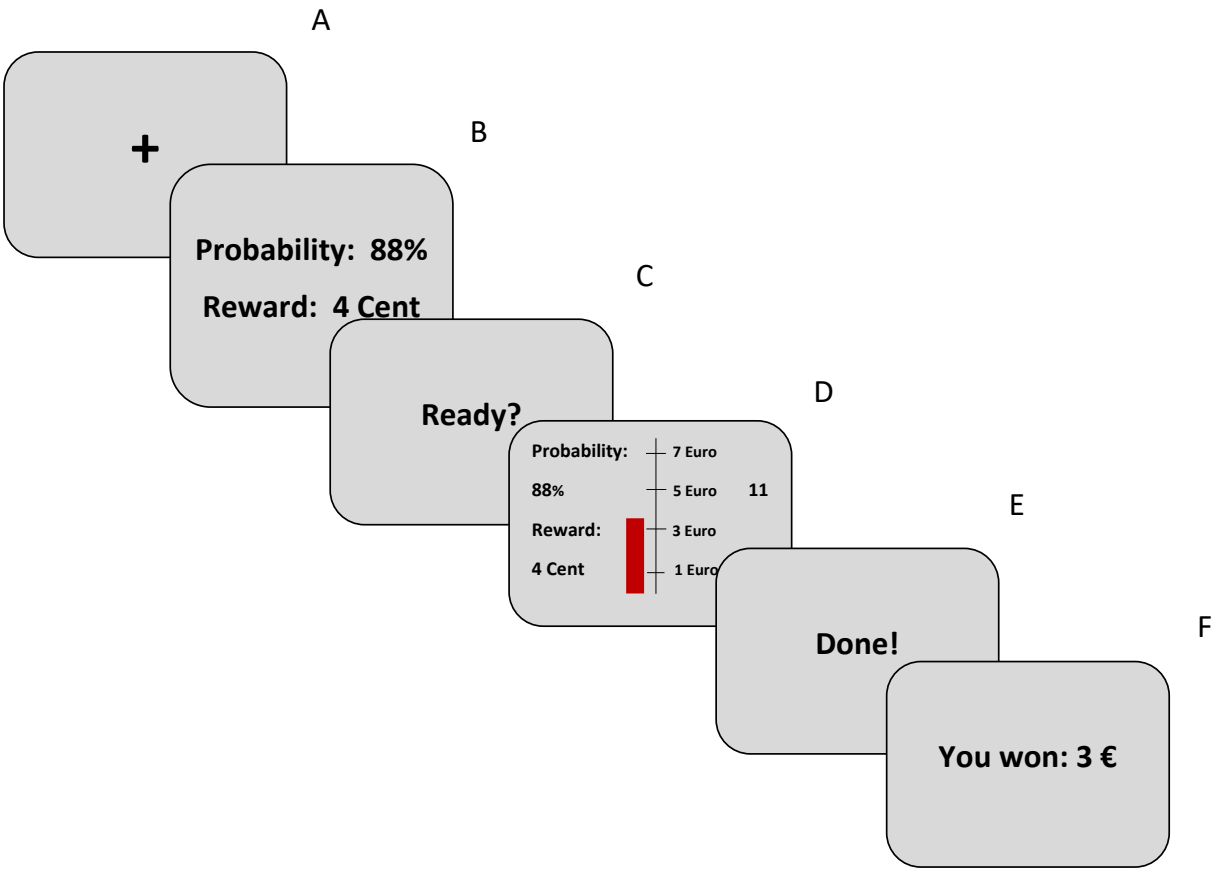

Abbildung 4. Schematische Darstellung eines Trials der modifizierten EEfRT. Zunächst erscheint ein Fixationskreuz für eine Sekunde (A). Dieses wird von einem Bildschirm gefolgt, der den möglichen Gewinnbetrag pro Klick und die Gewinnwahrscheinlichkeit anzeigt (B). Nach kurzer Präsentation eines Bildschirms zur Bereitmachung vor der Aufgabe (C, 1 Sekunde), erscheint die zentrale Aufgabe (D). Durch das Drücken der Leertaste wächst der angezeigte rote Balken zunehmend und anhand der zusätzlich angezeigten Skala kann jederzeit der gegenwärtig erreichte Geldbetrag überprüft werden. Zusätzlich wird ein Countdown angezeigt, der die verbliebene Zeit im aktuellen Trial wiedergibt (insgesamt immer 20 Sekunden pro Trial). Anschließend wir das Ende der Aufgabe signalisiert (E, 2 Sekunden) und ein Feedback über den gewonnenen Geldbetrag (F, 2 Sekunden) eingeblendet (eigene Darstellung).

1.3.2 Vorbefunde zur Reliabilität und Validität

Die EEfRT wurde seit ihrer Entwicklung in zahlreichen Studien eingesetzt und brachte ebenso zahlreiche Befunde hervor, die Ihre Validität belegen sollten – sowohl aus dem klinischen als auch aus dem nicht-klinischen Bereich. Geaney et al. (2015) konnten zeigen, dass der Anteil der HTC mit der Persönlichkeit assoziiert ist, u.a. mit der Ausprägung in der BAS–Skala und dem antizipatorischen Genuss (Geaney et al., 2015). Demnach zeigten z. B. Teilnehmer mit einer höheren Ausprägung in der BAS–Skala eine höhere Bereitschaft dazu, die schwere Aufgabe zu wählen. Andere Studien konnten diese Zusammenhänge jedoch nicht bestätigen (Horan et al., 2016; Anand et al., 2016; Kaack et al., 2020). In Ihrer Originalarbeit konnten Treadway et al. (2009) zeigen, dass der Anteil der HTC negativ mit selbstberichteter Depressivität und Anhedonie zusammenhängt. In diesem Kontext hat die EEfRT gerade auch durch klinische Studien und Untersuchungen von Patienten mit eingeschränkter Motivation vielfältige Nachweise ihrer Validität erhalten: So zeigten Patienten mit Depression (Treadway, Bossaller, Shelton et al., 2012; Yang et al., 2014), Schizophrenie (Fervaha et al., 2013; Barch et al., 2014; McCarthy et al., 2016), Psychosen (Chang et al., 2019), und Autismus (Damiano et al., 2012) eine geringere Bereitschaft, die schwere Aufgabe zu wählen. Auch auf neurophysiologischer Ebene konnte die EEfRT diverse Nachweise ihrer Validität erbringen. So konnten Hughes et al. (2015) zeigen, dass eine stärker ausgeprägte linksfrontale Asymmetrie im Ruhe-EEG mit einem höheren Anteil der HTC assoziiert war. Unter Berücksichtigung der methodischen und empirischen Einwände gegen die Erfassung der frontalen Asymmetrie im Ruhe-EEG (Wacker et al., 2013; Kuper et al., 2019) sind die aktuellen Befunde von Kaack et al. (2020) besonders interessant, da diese Autoren unterschiedliche Zusammenhänge zwischen einer stärkeren linksfrontale Aktivierung im Ruhe-EEG und während der Bearbeitung der EEfRT mit dem Anteil der HTC nachweisen konnten. Dabei hing eine stärker linksfrontale Aktivierung im Ruhe–EEG mit einem höheren Anteil der HTC in Trials mit niedriger Gewinnchance zusammen. Demgegenüber korrelierte eine stärker linksfrontale Aktivierung in

den ersten 5 Minuten während der Aufgabe mit einem generell höheren Anteil der HTC über die gesamte Aufgabe zusammen. Außerdem konnten Huang et al., (2016) zeigen, dass der Anteil der HTC positiv mit der Aktivität des NAcc korrelierte, welcher ebenfalls Teil des MCLDA ist.

Die aufgeführten Befunde machten die EEfRT für mich zur Aufgabe der Wahl für meine Dissertation. Dennoch sei an dieser Stelle bereits erwähnt, dass die EEfRT keinesfalls eine uneingeschränkt hohe Validität aufweist. Neben den häufig nur kleinen Stichproben war eine zentrale Kritik, welche letztlich zur Durchführung der Studien 3 und 4 führte, die Verwendung zahlreicher modifizierter Varianten der EEfRT, die aber nur in Ausnahmen auch auf Ihre tatsächlichen Auswirkungen hin untersucht wurden. Fast alle der zuvor genannten Studien haben kleinere oder größere Änderungen an der EEfRT vorgenommen, um die Aufgabe z. B. für bestimmte Teilnehmergruppen zugänglicher zu machen, oder die Aufgabe an spezielle Fragestellungen anzupassen. In Anlehnung an die Aufbereitung der entsprechenden Literatur für Studie 3 und 4 sei daher an dieser Stelle auf einige exemplarische Beispiele verwiesen: Yang et al. (2014) reduzierten die Anzahl der benötigten Tastendrücke, um die Aufgabe für Depressionspatienten zugänglicher zu machen. Damiano et al. (2012) haben das Zeitlimit während der Entscheidung zwischen der leichten und der schweren Aufgabe entfernt, Fervaha et al. (2013) haben eine individuell kalibrierte Anzahl benötigter Tastendrücke verwendet, Barch et al. (2014) haben die niedrige Gewinnwahrscheinlichkeit (12%) entfernt und Byrne und Ghaiumy Anaraky (2019) haben Trials hinzugefügt, bei denen die Teilnehmer statt zwischen zwei unterschiedlich hohen Gewinnen zwischen zwei unterschiedlich hohen Verlusten wählen mussten. Diese Auflistung stellt nur eine kleine Auswahl aller bereits an der EEfRT vorgenommenen Modifikationen dar (eine umfassendere Aufbereitung der bisherigen Modifikationen der EEfRT findet sich in Studie 3 und 4 - siehe Anhang C). Entsprechend erschien mir eine eben solche Untersuchung der von mir an der EEfRT vorgenommenen Modifikationen (siehe Abbildung 4) umso notwendiger.

2. Zielsetzung der vorliegenden Dissertation

Die erste Zielsetzung der vorliegenden Dissertation bestand in der Erlangung weiterer Erkenntnisse darüber, ob und in welcher Form die zuvor genannten neurophysiologischen Korrelate der Annäherungsmotivation (frontale Asymmetrie; MCLDA) auch in einem kausalen Zusammenhang mit dieser stehen. Hierfür habe ich zwei Studien durchgeführt. In Studie 1 sollte die frontale Asymmetrie mittels tDCS manipuliert werden und die Auswirkungen auf die Annäherungsmotivation auf Verhaltensebene in der EEfRT untersucht werden. In Studie 2 sollte mittels Gabe des niedrig dosierten D2-Rezeptor-Blockers Sulpirid die DA-Konzentration im MCLDA erhöht werden. Die Auswirkungen auf die Annäherungsmotivation sollten wiederum auf Verhaltensebene nachgewiesen werden. Hierfür wurde eine modifizierte Variante der EEfRT eingesetzt, welche einige Nachteile der originalen EEfRT ausgleichen sollte.

Die zweite Zielsetzung meiner Dissertation war die Überprüfung der Reliabilität und Validität der originalen und meiner modifizierten Variante der EEfRT. Hierfür habe ich zwei weitere Studien durchgeführt. In Studie 3 wurden beide Varianten der EEfRT innerhalb eines einzelnen experimentellen Settings eingesetzt, um diese direkt miteinander vergleichen zu können. Zudem habe ich u.a. einige Fragebogenverfahren zur Erfassung der Annäherungsmotivation eingesetzt, um die Validität der beiden Varianten zu überprüfen. In Studie 4 schließlich habe ich die Reliabilität und Validität der originalen EEfRT in einer deutlich größeren Stichprobe erneut untersucht. Die größere Stichprobe sollte dabei die statistische Power zur Entdeckung auch kleinerer Zusammenhänge erhöhen.

Die folgenden Abschnitte beschreiben die Ziele, Methodik und Ergebnisse aller vier Studien, wobei die Studien 3 und 4 innerhalb der dritten Veröffentlichung zusammengefasst wurden.

3. Studie 1

Ohmann, H. A., Kuper, N., & Wacker, J. (2018). Left frontal anodal tDCS increases approach motivation depending on reward attributes. *Neuropsychologia, 119,* 417–423. https://doi.org/10.1016/j.neuropsychologia.2018.09.002

3.1 Hintergrund

Diverse Studien deuten auf einen Zusammenhang zwischen der frontalen Asymmetrie, also der asymmetrischen Aktivierung frontaler Hirnregionen, und der individuellen Annäherungsmotivation hin. Dabei wird angenommen, dass eine stärker linksfrontale Aktivierung mit einer größeren Annäherungsmotivation und eine stärker rechtsseitige Aktivierung mit einer größeren Vermeidungsmotivation assoziiert ist (Harmon-Jones & Gable, 2018; Rutherford & Lindell, 2011). Wenngleich ein Zusammenhang zwischen der frontalen Asymmetrie und der Verarbeitung von Belohnungen ebenso nachgewiesen wurde (Gorka et al, 2015; Miller & Tomarken, 2001; Sobotka et al., 1992), wie ein Zusammenhang zu Persönlichkeitseigenschaften (Wacker et al., 2013; Wacker, 2018), welche mit Annäherungsmotivation assoziiert sind, bleibt der kausale Zusammenhang bisher unklar (Kelley et al., 2017). Neben Studien, welche die Modellannahmen der frontalen Asymmetrie bestätigen (Chrysikou et al., 2016; Hortensius et al., 2012; Kelley, Hortensius & Harmon-Jones, 2013; Kelley, Eastwick, Harmon-Jones et al., 2015; Riva et al., 2015), existieren zahlreiche Studien, die diesen Annahmen entgegenstehen (Fecteau et al., 2007; Russo et al., 2017; Shen et al., 2016; Soutschek et al., 2018; Ye et al., 2015). Insofern war das Ziel meiner ersten Studie, weitere Erkenntnisse über den kausalen Zusammenhang zwischen der frontalen Asymmetrie und der Annäherungsmotivation zu erlangen. Ich erwartete, dass die Stimulation des linken dlPFC mittels anodaler tDCS, welche eine Zunahme der linksfrontalen Aktivität bewirken sollte, zu einer Steigerung der Anstrengungsbereitschaft als Maß der Annäherungsmotivation führen würde.

3.2 Methodik

Wir testeten insgesamt 60 gesunde rechtshändige Studierende (63% weiblich) im Alter zwischen 18 und 35 Jahren in einem Messwiederholungsdesign an zwei Tagen mit mindestens einer Woche Abstand und stimulierten die Teilnehmer an einem Tag für 20 Minuten mittels einer anodalen tDCS (Spannung: 1 mA) über dem linken dlPFC. Die Kathode wurde dabei über dem rechten supraorbitalen Areal angebracht (Vergleich: Abbildung 2). Die Position der Anode wurde dabei mittels EEG–Kappe bestimmt (F3–Position im 10–20 System; De Witt et al., 2018) An dem anderen Untersuchungstag erhielten die Teilnehmer eine SHAM–Stimulation (Kontrollbedingung). Die Reihenfolge der beiden Stimulationen war dabei randomisiert. Während und nach der Stimulation absolvierten die Teilnehmer die originale EEfRT (siehe Abschnitt 1.3.1), um die Annäherungsmotivation auf Verhaltensebene erfassen zu können – je ein 15-Minuten Block während der Stimulation und ein 15-Minuten Block nach der Stimulation. Die abhängige Variable war dabei der Anteil der HTC.

3.3 Ergebnisse

Die EEfRT zeigte auch in einem unserem Messwiederholungsdesign die üblichen Haupteffekte der Belohnungshöhe und der Gewinnwahrscheinlichkeit. Es konnte jedoch kein Haupteffekt der Stimulationsbedingung gefunden werden. Dennoch zeigte sich, dass die anodale tDCS eine Zunahme der Anstrengungsbereitschaft innerhalb der EEfRT in Abhängigkeit der Belohnungseigenschaften, also der Belohnungshöhe und der Gewinnwahrscheinlichkeit, bewirkte (siehe Modelle 8 und 9 in Tabelle 1). Dabei deuten die Interaktionen daraufhin, dass die anodale tDCS die Anstrengungsbereitschaft insbesondere in solchen Trials mit geringer Gewinnwahrscheinlichkeit und solchen mit geringen Belohnungen erhöhte. Insofern der Vergleich der anodalen tDCS mit der SHAM-Stimulation von zentraler Bedeutung war, prüfte ich zusätzlich, ob die Stimulationsbedingung durch die Teilnehmer korrekt erraten werden konnte. Dies war bei 66,67% der Teilnehmer der Fall und somit überzufällig. Dies hatte jedoch keinen Einfluss auf den eigentlichen Effekt der anodalen tDCS (siehe Tabelle 2).

Tabelle 1. GEE-Modelle zum Vergleich der beiden tDCS – Bedingungen (anodale Stimulation VS SHAM) und deren Einfluss auf den Anteil der HTC in der EEfRT in Studie 1 (Ohmann, Kuper & Wacker, 2018).

Effect	β	*se*	χ^2	*p*
Model 7				
tDCS Condition	0.05	0.10	0.27	.603
Model 8				
tDCS Condition	0.06	0.10	0.38	.540
tDCS Condition × Reward Magnitude	0.15	0.06	6.23	**.013**
Model 9				
tDCS Condition	0.19	0.14	1.96	.162
tDCS Condition × Probability 50%[a]	− 0.04	0.15	0.07	.791
tDCS Condition × Probability 88%[a]	− 0.45	0.21	4.60	**.032**
Model 10				
tDCS Condition	− 0.11	0.13	0.65	.421
tDCS Condition × Block	0.11	0.15	0.59	.442
Model 11				
tDCS Condition	0.43	0.53	0.66	.418
tDCS Condition × Study Day	− 0.95	1.05	0.82	.365
Model 12				
tDCS Condition	0.35	0.53	0.43	.513
tDCS Condition × Block	0.17	0.21	0.66	.417
tDCS Condition × Study Day	− 0.92	1.02	0.82	.366
tDCS Condition × Block × Study Day	− 0.08	0.23	0.11	.735

Note. All models included probability (categorical), reward magnitude, trial number, block and hand as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a] Estimates were computed in relation to the low (12%) reward probability level, the parameters for which are therefore redundant.

Tabelle 2. GEE-Modelle zur Überprüfung des Einflusses der Erkennung der tDCS – Bedingungen (korrekt erraten VS nicht korrekt erraten) und deren Einfluss auf den Anteil der HTC in der EEfRT in Studie 1 (Ohmann, Kuper & Wacker, 2018).

Effect	β	*se*	χ^2	*p*
Model 13				
Guessed Correctly	− 0.64	0.68	0.89	.344
Guessed Correctly × tDCS Condition	− 0.08	0.23	0.13	.719
Model 14				
Guessed Correctly	0.37	0.44	0.57	.449
Guessed Correctly × tDCS Condition	0.29	0.33	0.75	.386
Guessed Correctly × tDCS Condition × Reward Magnitude	− 0.28	0.19	2.14	.143
Model 15				
Guessed Correctly	− 0.28	0.68	0.16	.686
Guessed Correctly × tDCS Condition	− 0.17	0.29	0.32	.570
Guessed Correctly × tDCS Condition × Probability 50%[a]	0.00	0.27	0.00	.999
Guessed Correctly × tDCS Condition × Probability 88%[a]	0.27	0.38	0.49	.482

Note. All models included probability (categorical), reward magnitude, trial number, block and hand as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a] Estimates were computed in relation to the low (12%) reward probability level, the parameters for which are therefore redundant.

3.4 Diskussion

Die Steigerung der Anstrengungsbereitschaft als Folge der anodalen tDCS über dem linken dlPFC unterstützt die Annahme eines kausalen Zusammenhangs zwischen frontaler Asymmetrie und der Annäherungsmotivation auf Verhaltensebene. Der Einfluss der Belohnungseigenschaften deutet auf eine Interkation zwischen der durch tDCS bewirkten erhöhten Erregbarkeit der Neurone und der durch die Aufgabe selber bewirkten Aktivität hin und unterstützt entsprechende Annahmen (Bortoletto et al., 2015). Eine entscheidende Limitation dieser (und vieler anderer tDCS–Studien) ist die mangelnde Überprüfung der tatsächlichen Veränderung der Hirnaktivität durch tDCS. Weitere Studien sollten den gefundenen Zusammenhang daher genauer untersuchen und dabei kombinierte Verfahren verwenden (z. B. tDCS und TMS), um die Effekte auf neuronaler Ebene besser abbilden zu können. Eine weitere Limitation der Studie steht im Zusammenhang mit dem Design der originalen EEfRT. Da die Dauer eines Blocks fixiert ist (hier: 15 Minuten) und die leichte Aufgabe mit 7 Sekunden deutlich kürzer ist als die schwere Aufgabe mit 21 Sekunden, ergeben sich hierdurch strategische Ansätze für solche Teilnehmer, die erkennen, dass die Wahl der schweren Aufgabe nicht automatisch zu einem höheren Gesamtgewinn führt. Entsprechende Rückmeldungen durch die Teilnehmer haben uns auf die Fährte des Problems geführt. Insofern plante ich die Überarbeitung der EEfRT, um für meine zweite Studie eine Version einsetzen zu können, welche weniger durch Strategien beeinflusst wird.

4. Studie 2

Ohmann, H. A., Kuper, N., & Wacker, J. (2020). A low dosage of the dopamine D2-receptor antagonist sulpiride affects effort allocation for reward regardless of trait extraversion. *Personality Neuroscience*, *3, E7*. https://doi.org/10.1017/pen.2020.7

4.1 Hintergrund

DA ist mit verschiedenen Aspekten der Verarbeitung von Belohnungen assoziiert, wie u.a. mit zielgerichtetem Verhalten (Depue & Collins, 1999), verschiedenen Aspekten der Motivation (Berridge & Kringelbach, 2008; Salamone et al., 2006) und der Initiierung von Verhaltensweisen, die zu größtmöglichen Belohnungen führen (Nicola et al., 2004; Treadway & Zald, 2011; Walton et al., 2006). Die Annahmen zur Manipulation der Annäherungsmotivation mittels des selektiven D2-Rezeptor-Blockers Sulpirid hingegen basieren auf Studien, welche sowohl was dessen Dosierung als auch was die Operationalisierung der Annäherungsmotivation angeht, sehr unterschiedliche Ansätze gewählt haben (Weber et al., 2016; Ojala et al., 2018; Diederen et al., 2017; Kahnt, et al., 2015; Eisenegger et al., 2014). Dabei wird grundsätzlich angenommen, dass Sulpirid je nach Dosierung unterschiedliche Effekte auf die DA-Konzentration im MCLDA und damit auf die Annäherungsmotivation hat. Demnach steigern geringe Dosierungen die DA-Konzentration (Tagliamonte et al., 1975; Rankin et al., 2009) und höhere Dosierungen verringern die DA-Konzentration (Eisenegger et al., 2014; Boschen et al., 2015). Daher war es das Ziel meiner zweiten Studie, den kausalen Zusammenhang zwischen DA-Konzentration und Anstrengungsbereitschaft als Maß der Annäherungsmotivation genauer zu untersuchen. Da frühere Befunde einen moderierenden Effekt der Persönlichkeit nachweisen konnten (insbesondere Extraversion: z. B. Chavanon et al., 2013), habe ich diese ebenfalls berücksichtigt. Ich erwartete eine Steigerung der Anstrengungsbereitschaft als Maß der Annäherungsmotivation auf Grund der mit geringen Dosierungen assoziierten Effekte.

4.2 Methodik

Im Rahmen der preregistrierten Studie (Methoden und Hypothesen: https://osf.io/e5fn9) habe ich insgesamt 203 gesunde rechtshändige Männer im Alter zwischen 18 und 35 Jahren im Rahmen eines doppelblinden und randomisierten Versuchsdesigns untersucht. Dabei nahmen 102 Teilnehmer zu Beginn der Untersuchung eine Kapsel mit 200mg Sulpirid ein (Experimentalgruppe) und 101 Teilnehmer nahmen eine Kapsel mit einem Placebo ein (Kontrollgruppe). Die Testung erfolgte in kleinen Gruppen von 3-4 Versuchsteilnehmern, welche die Aufgaben jedoch in getrennten Kabinen bearbeiteten. Aufgrund der Medikamenteneinnahme wurde besonderer Wert auf die Gesundheit der Teilnehmer gelegt, welche in einer Voruntersuchung mittels Erhebung körperlicher und psychischer Erkrankungen erfasst wurde. Die Anstrengungsbereitschaft als Maß der Annäherungsmotivation wurde mittels einer modifizierten Variante der EEfRT erfasst (siehe Abbildung 4), welche keine Auswahl zwischen zwei unterschiedlich schwierigen Aufgaben mehr bot. Stattdessen wurde die Belohnungshöhe pro Tastendruck zwischen den Durchgängen variiert, deren Dauer nun immer 20 Sekunden betrug. Die Aufgabe war auf zwei Blöcke aufgeteilt, einer wurde mit der linken Hand und der andere mit der rechten Hand absolviert. Die Gewinnwahrscheinlichkeit wurde in den gleichen drei Kategorien wie in der originalen EEfRT variiert (12%/ 50%/ 88%). Die abhängige Variable der modifizierten EEfRT war die durchschnittliche Anzahl der Tastendrücke. Zudem habe ich auch die motorischen Fähigkeiten der Teilnehmer berücksichtigt, von denen ich annahm, dass sie maßgeblichen Anteil an der erreichten Anzahl der Tastendrücke haben würden. Hierfür habe ich zusätzliche „motorische Trials“ eingesetzt. In diesen sollten die Teilnehmer so schnell wie möglich die Leertaste drücken, es wurde jedoch nur ein Countdown (20 Sekunden) angezeigt und es konnte kein Geld gewonnen werden.

4.3 Ergebnisse

Zunächst lässt sich festhalten, dass die Haupteffekte der Belohnungseigenschaften ein vergleichbares Muster zu denen der originalen EEfRT aufwiesen. Sowohl die Gewinnwahrscheinlichkeit als auch die Belohnungshöhe waren hoch signifikante Prädiktoren der durchschnittlichen Anzahl der Tastendrücke (siehe Abbildung 5 und 6). Die Reliabilität der modifizierten EEfRT konnte zudem als zufriedenstellend bezeichnet werden und rangierte (aufgeteilt nach verschiedenen Trial-Kategorien für unterschiedliche Belohnungshöhen und Gewinnwahrscheinlichkeiten) zwischen Rel. = .67 und .87. Entgegen unserer Erwartungen zeigte die Experimentalgruppe nach Einnahme von 200mg Sulpirid eine geringere Anstrengungsbereitschaft innerhalb der modifizierten EEfRT im Vergleich zu der Kontrollgruppe (siehe Abbildung 5 und 6), der Effekt wurde zudem nicht wie erwartet durch die Belohnungseigenschaften moduliert. Zudem hatte auch die Persönlichkeit (insbesondere Extraversion) in dieser Studie keinen moderierenden Effekt. Jedoch zeigten Teilnehmer mit einer höheren Ausprägung in der Extraversion als auch Teilnehmer mit einer höheren Ausprägung in der BAS–Skala eine höhere Anstrengungsbereitschaft in Trials mit niedriger Gewinnwahrscheinlichkeit (siehe Tabelle 3).

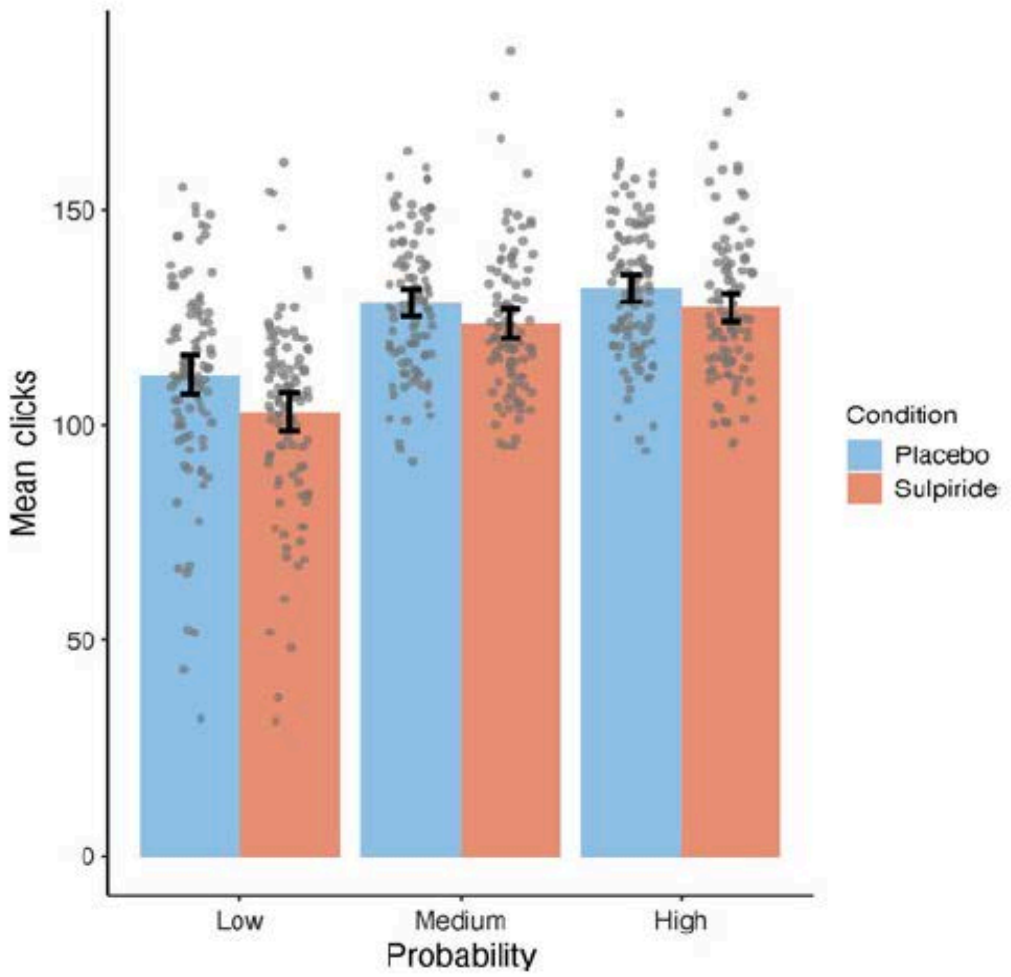

Abbildung 5. Die durchschnittliche Anzahl der Tastendrücke in der modifizierten EEfRT, aufgegliedert nach der Gewinnwahrscheinlichkeit in Studie 2. Dabei werden die niedrige Gewinnwahrscheinlichkeit (links), die mittlere Gewinnwahrscheinlichkeit (mittig) und die hohe Gewinnwahrscheinlichkeit (rechts) zwischen der Experimentalgruppe (rot, Sulpirid) und der Kontrollgruppe (blau, Placebo) verglichen. Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder, die Fehlerbalken stellen das 95% - Konfidenzintervall der Mittelwerte dar (Ohmann, Kuper & Wacker, 2020).

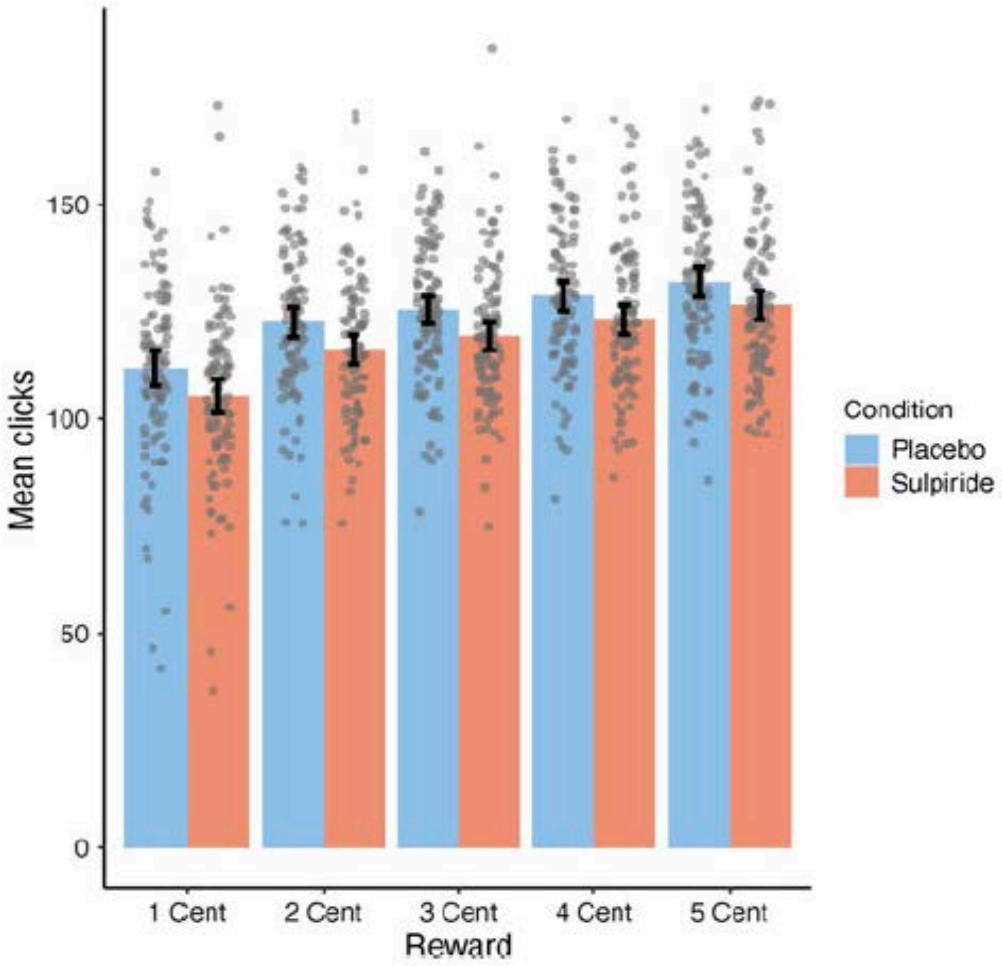

Abbildung 6. Die durchschnittliche Anzahl der Tastendrücke in der modifizierten EEfRT, aufgegliedert nach der Gewinnhöhe pro Tastendruck in Studie 2. Die Gewinnhöhe reicht von 1 Cent pro Tastendruck (ganz links) bis zu 5 Cent pro Tastendruck (ganz rechts). Verglichen werden die Experimentalgruppe (rot, Sulpirid) und die Kontrollgruppe (blau, Placebo). Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder, die Fehlerbalken stellen das 95% - Konfidenzintervall der Mittelwerte dar (Ohmann, Kuper & Wacker, 2020).

Tabelle 3. Korrelationen zwischen der durchschnittlichen Anzahl der Tastendrücke und den selbstberichteten Persönlichkeitseigenschaften in Studie 2 (Ohmann, Kuper & Wacker, 2020).

	Reward probability		
Trait variable	12%	50%	88%
BAS	**0.212****	0.124	0.103
BIS	−0.081	0.081	0.052
Extraversion	**0.193****	0.051	0.054
Openness	**0.159***	0.039	0.024
Conscientiousness	0.113	0.033	0.023
Neuroticism	−0.093	0.072	0.062
Agreeableness	−0.052	0.035	−0.016

Note. EEfRT = Effort Expenditure for Rewards Task; BAS = behavioral activation system; BIS = behavioral inhibition system scale; significant effects in bold. * $p < .05$ ** $p < .01$.

4.4 Diskussion

Während einerseits der gefundene Haupteffekt der Einnahme von 200mg Sulpirid in eine unserer Hypothese entgegengesetzten Richtung wies, sich die Anstrengungsbereitschaft also verringerte, konnten doch zumindest Hinweise auf einen kausalen Zusammenhang zwischen der manipulierten DA-Konzentration und der Anstrengungsbereitschaft gefunden werden. Gleichwohl die Persönlichkeit keinen moderierenden Effekt hatte, wurden jedoch frühere Befunde bestätigt, die einen Zusammenhang zwischen der Persönlichkeit und der Anstrengungsbereitschaft speziell in Trials mit geringer Belohnungswahrscheinlichkeit aufgezeigt haben (Geaney et al., 2015). Insgesamt warfen die Ergebnisse viele Fragen bzgl. der gefundenen Zusammenhänge auf. Eine Limitation (analog zur Studie 1) ist die fehlende Überprüfung der tatsächlich auf neurophysiologischer Ebene bewirkten Effekte (DA–Konzentration im MCLDA). Somit ergab sich aus dieser Studie das zweite Ziel meiner Dissertation – eine genaue Überprüfung der Reliabilität und der Validität der EEfRT.

5. Studien 3 + 4

Ohmann, H. A., Kuper, N., & Wacker, J. Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT). Submitted to *Journal of Research in Personality.*

5.1 Hintergrund

Die EEfRT ist ein häufig eingesetztes Messverfahren zur Erfassung der Anstrengungsbereitschaft als Maß der Annäherungsmotivation. Dabei haben viele Studien in den vergangenen Jahren Befunde hervorgebracht, welche die Validität der Aufgabe belegen (siehe auch Abschnitt 1.3.2). Als Vorbereitung auf die Studien 3 und 4 habe ich eine umfangreiche Sichtung der Literatur zur EEfRT durchgeführt und die Literatur gezielt nach Modifikationen an der EEfRT, sowie nach Angaben zur Reliabilität und Validität ausgewertet. Herausgekommen ist die ernüchternde Erkenntnis, dass lediglich eine Studie einen direkten Vergleich zwischen der originalen und einer modifizierten EEfRT vorgenommen hat (Lopez-Gamundi & Wardle, 2018) und nur 3 Studien inklusive meiner zweiten Studie die Reliabilität der EEfRT angegeben haben (Reddy et al., 2015; Horan et al., 2015; Ohmann et al., 2020), wenngleich diese durchweg als zufriedenstellend zu bezeichnen ist. Auch in Studie 2 habe ich eine modifizierte Variante der EEfRT eingesetzt. Zwar konnte dort wie bei vielen anderen Studien gezeigt werden, dass die grundsätzlichen Parameter der Aufgabe vergleichbar funktionieren (z. B. Belohnungshöhe, Gewinnwahrscheinlichkeit), dennoch ist es nicht unwahrscheinlich, dass die Auswirkungen auf das Verhalten der Teilnehmer unterschätzt wurde. Zudem sind gerade die Zusammenhänge zwischen der EEfRT und selbstberichteter Annäherungsmotivation (z. B. BAS) umstritten, während einige Studien die Zusammenhänge bestätigen (Geaney et al., 2015; Ohmann et al., 2020), konnten andere diese nicht belegen (Horan et al., 2015; Anand et al., 2016; Kaack et al., 2020). Studien 3 und 4 sollten daher die Validität und Reliabilität der beiden von mir eingesetzten Varianten der EEfRT in zwei ausreichend großen Stichproben untersuchen.

5.2 Methodik

In Studie 3 wurden insgesamt 120 gesunde Teilnehmer (78,3% weiblich) im Alter zwischen 18 und 35 Jahren mit beiden Varianten der EEfRT getestet, um diese direkt miteinander vergleichen zu können. Die Reliabilität wurde mittels Split-Half-Korrelationen untersucht. Zudem wurden ein weiterer Test zur Erfassung der Risikobereitschaft (Balloon-Analogue Risk Task; Lejuez et al., 2002), sowie Fragebogen zur Erfassung der Annäherungsmotivation (insbesondere die BIS/BAS–Skalen) und einer Nachbefragung zur Erhebung der verwendeten Strategien eingesetzt, um die Validität der beiden Aufgaben genauer untersuchen zu können. Die Reihenfolge der beiden Varianten der EEfRT war dabei randomisiert und es wurden zusätzlich vor jeder der beiden Varianten Trials zur Erfassung der motorischen Fähigkeiten eingesetzt. In Studie 4 wurden insgesamt 394 gesunde Teilnehmer (68,2% weiblich) zwischen 18 und 50 Jahren untersucht. Ziel der vierten Studie war es, die Reliabilität und Validität der originalen EEfRT in einer großen Stichprobe erneut zu untersuchen. Dafür wurden ebenfalls die BIS/BAS–Skalen eingesetzt. Die Datensätze und Hauptanalysen beider Studien sind frei verfügbar: https://osf.io/35k2w/?view_only=1f315859028c471787a96e153f5ac43a.

5.3 Ergebnisse

Die Reliabilität beider Varianten der EEfRT konnte in beiden Studien als zufriedenstellend bewertet werden und rangierte (aufgeteilt nach verschiedenen Trial-Kategorien) zwischen Rel. = .73 und .97. Auch die grundsätzlichen Parameter beider Aufgaben (Belohnungshöhe, Gewinnwahrscheinlichkeit) zeigten die erwarteten Muster (siehe Abbildung 7 und 8 für den Effekt der Belohnungshöhe in Studie 3). Es konnten zwar Zusammenhänge zwischen Persönlichkeit und Aufgabenparametern gefunden werden, diese stimmten aber nicht mit früheren Studien überein. So zeigte die BAS-Skala in keiner der Aufgaben und Studien einen Zusammenhang zum Verhalten in Trials mit geringer Belohnungswahrscheinlichkeit (siehe Abbildung 9). Die Zusammenhänge zwischen beiden Aufgaben waren signifikant, die Korrelationen aber generell eher niedrig (siehe Abbildung 10).

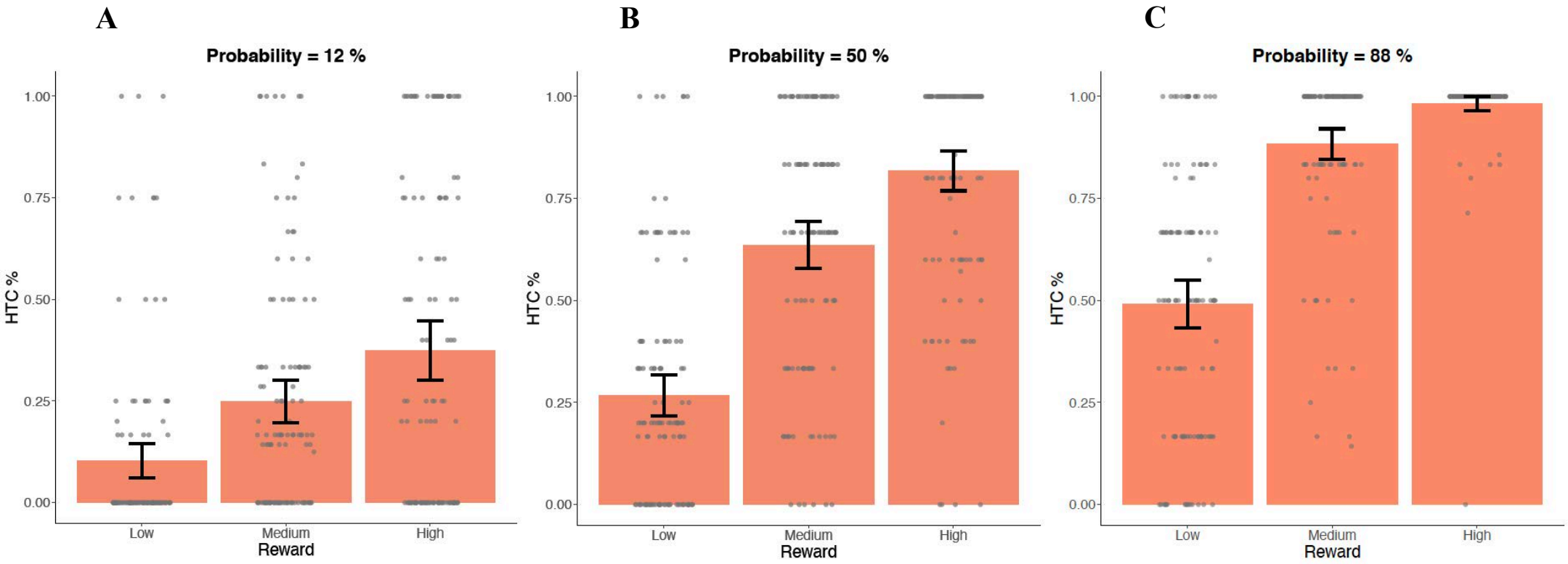

Abbildung 7. Prozentualer Anteil der Wahl der schweren Aufgabe (HTC) in der originalen EEfRT für die verschiedenen Belohnungshöhen (niedrig/ mittel/ hoch) im Vergleich zwischen den verschiedenen Gewinnwahrscheinlichkeiten (**A – links** :12%/ **B - mittig**: 50%/ **C - rechts**: 88%) in Studie 3. Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder, die Fehlerbalken stellen das 95% - Konfidenzintervall der Mittelwerte dar (Ohmann, Kuper & Wacker, eingereicht).

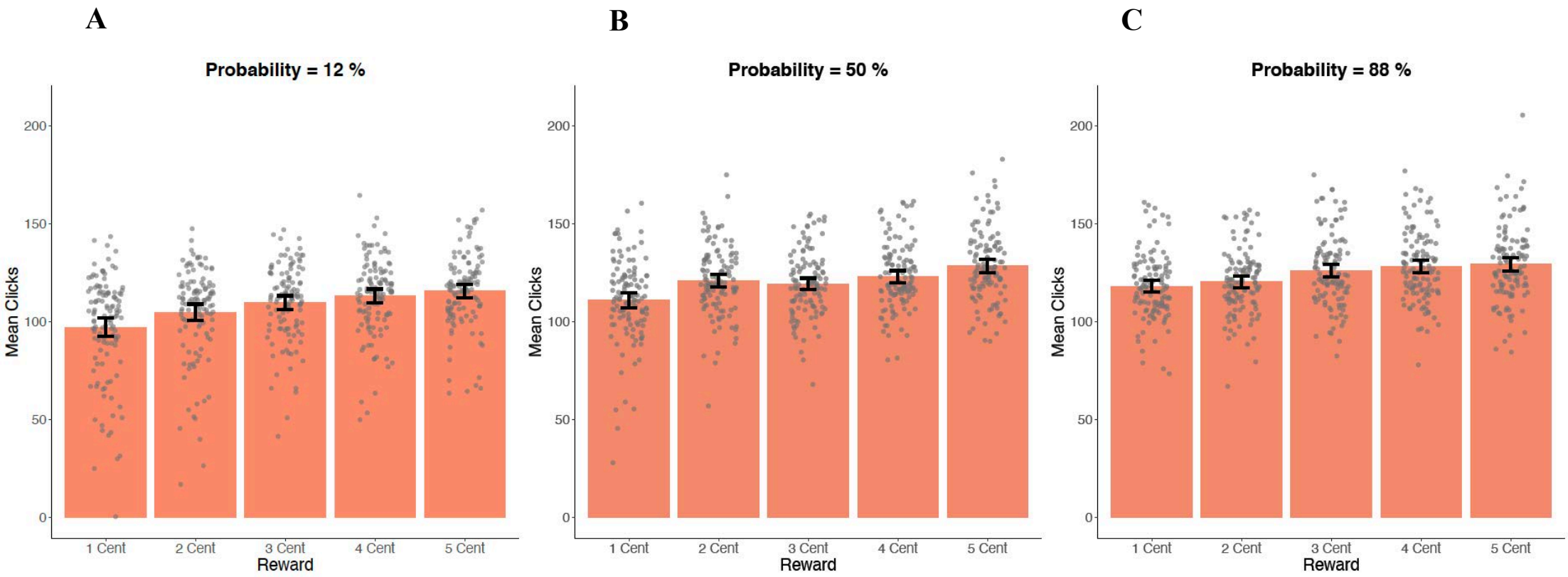

Abbildung 8. Durchschnittliche Anzahl der Tastendrücke in der modifizierten EEfRT für die verschiedenen Belohnungshöhen (von 1 Cent bis 5 Cent pro Tastendruck) im Vergleich zwischen den verschiedenen Gewinnwahrscheinlichkeiten (**A – links** :12%/ **B - mittig**: 50%/ **C - rechts**: 88%) in Studie 3. Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder, die Fehlerbalken stellen das 95% - Konfidenzintervall der Mittelwerte dar (Ohmann, Kuper & Wacker, eingereicht).

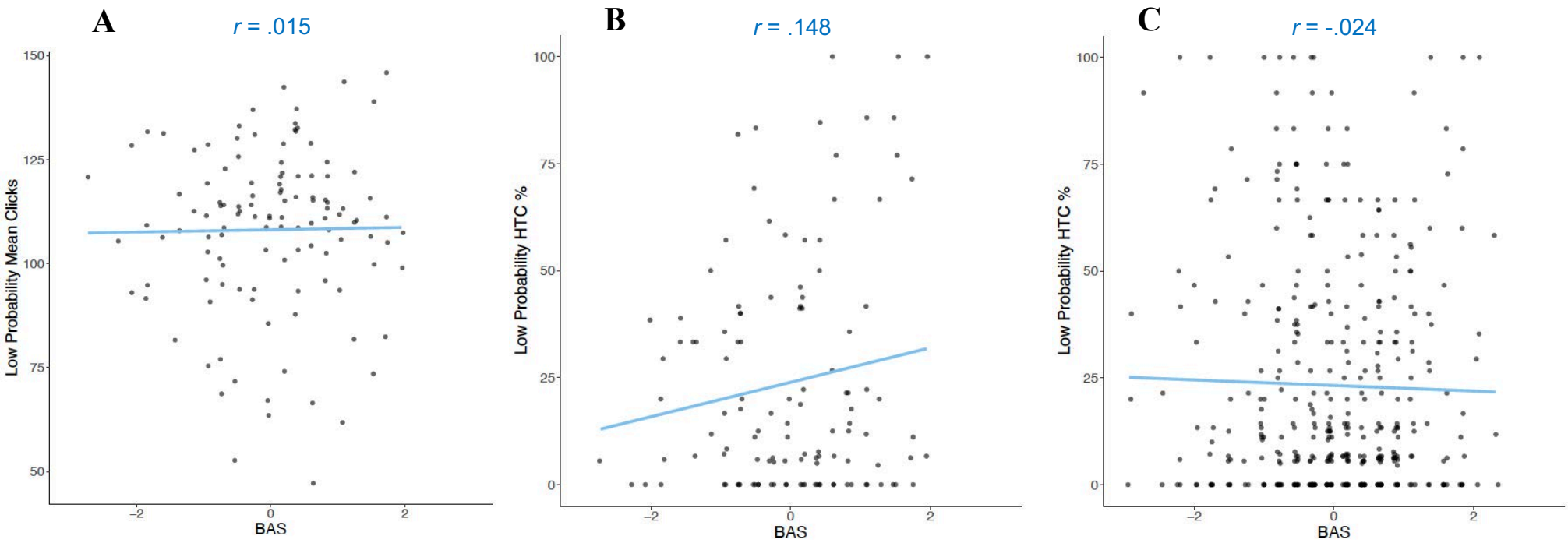

Abbildung 9. Pearson-Korrelationen zwischen den erreichten Werten in der BAS–Skala (z-standardisiert) und der durchschnittlichen Anzahl der Tastendrücke in der modifizierten EEfRT in Studie 3 (**A - links**) und dem Anteil der Wahl der schweren Aufgabe (HTC) in der originalen EEfRT (Studie 3: **B - mittig** / Studie 4: **C - rechts**). Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder (Ohmann, Kuper & Wacker, eingereicht).

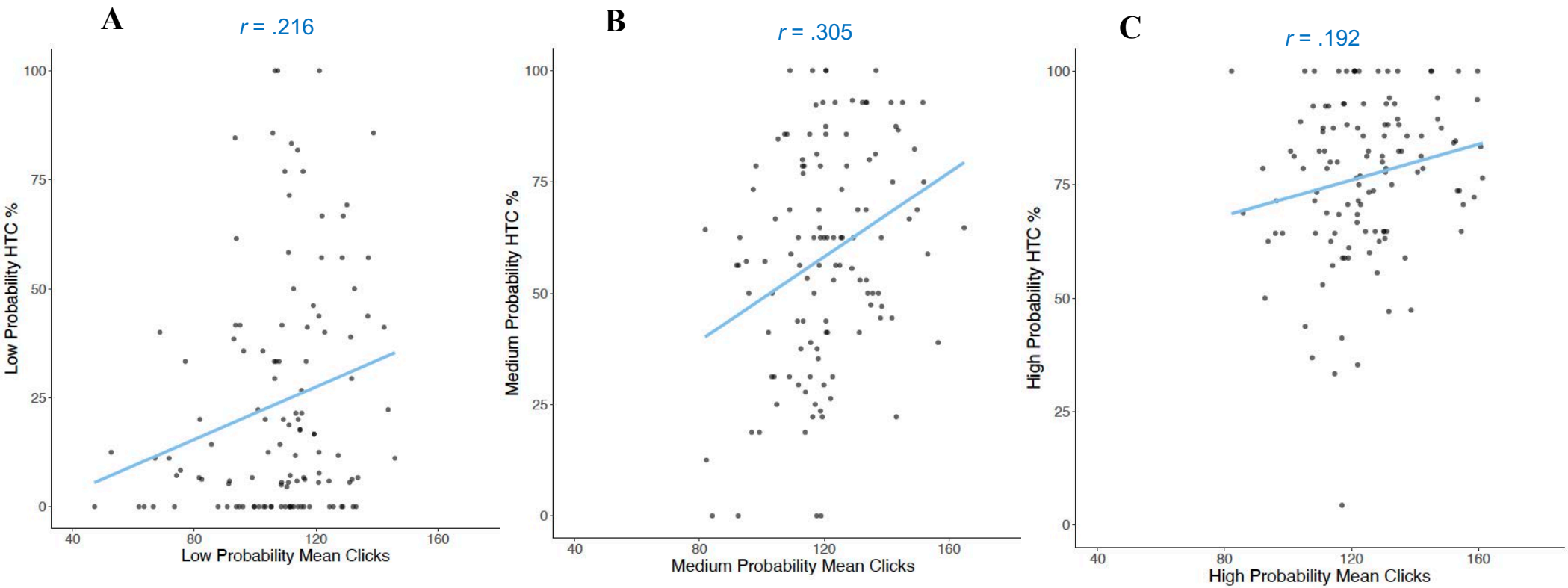

Abbildung 10. Pearson-Korrelationen zwischen der durchschnittlichen Anzahl der Tastendrücke in der modifizierten EEfRT in Studie 3 und dem Anteil der Wahl der schweren Aufgabe (HTC) in der originalen EEfRT in Studie 3 aufgeteilt nach den verschiedenen Gewinnwahrscheinlichkeiten (**A – links** :12%/ **B - mittig**: 50%/ **C - rechts**: 88%). Die Punkte geben die individuellen Datenpunkte der Teilnehmer wieder (Ohmann, Kuper & Wacker, eingereicht).

5.4 Diskussion

Die Ergebnisse beider Studien deuten zunächst einmal daraufhin, dass beide Varianten der EEfRT eine zufriedenstellende Reliabilität aufweisen. Außerdem korrelieren die Verhaltensmaße beider Aufgaben signifikant miteinander, so dass ein tatsächlicher konzeptueller Zusammenhang zwischen beiden Aufgaben angenommen werden kann. Dies wird zusätzlich durch die vergleichbaren Ergebnismuster in Bezug auf die grundlegenden Variablen der Aufgabe (z. B. Belohnungshöhe und Gewinnwahrscheinlichkeit) bestätigt. Jedoch liegen die Korrelationen zwischen beiden Aufgaben (aufgeteilt nach verschiedenen Trial-Kategorien) nur zwischen .160 und .305 und sind somit allgemein eher als niedrig einzustufen. Somit scheint die Varianz der Verhaltensmaße in beiden Aufgaben zu einem beachtlichen Anteil durch unterschiedliche Faktoren bedingt zu sein. Die Ergebnisse in Bezug auf die Validität sind insgesamt eher als negativ zu bezeichnen. Die gefundenen Zusammenhänge zur Persönlichkeit stimmten nicht mit früheren Studien überein. Die Ergebnisse deuten auf eine komplexe Interaktion zwischen Persönlichkeit, Studiendesign und Aufgabenparametern hin. Demnach können beide Varianten der EEfRT zwar als grundsätzlich reliable Messinstrumente empfohlen werden, jedoch bedarf es unbedingt weiterer Forschung, um die tatsächlichen Zusammenhänge besser verstehen zu können.

6. Allgemeine Diskussion

Die beiden Ziele meiner Dissertation waren es, einerseits neue Erkenntnisse bzgl. der neurophysiologische Basis der Annäherungsmotivation zu gewinnen und andererseits die Reliabilität und Validität der beiden eingesetzten Messinstrumente genauer zu erforschen. In den folgenden Abschnitten möchte ich daher die Ergebnisse meiner Studien zunächst getrennt nach diesen beiden Zielen einordnen und dann zu einem Gesamtfazit kommen.

6.1 Die neurophysiologische Basis der Annäherungsmotivation

Studien 1 und 2 haben zwei verschiedene Methoden zur Manipulation (tDCS, Sulpirid) der mit der Annäherungsmotivation assoziierten neurophysiologischen Prozesse eingesetzt. In Studie 1 habe ich den linken dlPFC der Teilnehmer mittels anodaler tDCS stimuliert und in einem Messwiederholungsdesign mit einer SHAM-Stimulation verglichen. Die Ergebnisse zeigten, dass die Stimulation einen positiven Effekt auf die Anstrengungsbereitschaft innerhalb der EEfRT hatte. Dieser Effekt war jedoch abhängig von der Belohnungshöhe und der Gewinnwahrscheinlichkeit. Anodale tDCS führte nur in Durchgängen mit geringer Belohnungshöhe und geringer Gewinnwahrscheinlichkeit zu einer erhöhten Anstrengungsbereitschaft und somit zu einer höheren Annäherungsmotivation. Insofern unterstützen die Befunde der ersten Studie die grundsätzliche Annahme, dass eine stärker linksfrontale Aktivität mit einer höheren Annäherungsmotivation und eine stärker rechtsfrontale Aktivität mit einer höheren Vermeidungsmotivation assoziiert sind (Harmon-Jones & Gable, 2018; Rutherford & Lindell, 2011). Dabei ist zu beachten, dass die Effekte der Stimulation der frontalen Asymmetrie in Studie 1 sowohl „Online“ (während der Aufgabe) und „Offline“ (nach der Aufgabe) nachweisbar waren. Insofern unterstützen die Ergebnisse auch solche Befunde, die langanhaltende Effekte durch tDCS nachweisen konnten (Sela & Lavidor, 2014). Die Interaktionen der Effekte mit der Belohnungshöhe und der Gewinnwahrscheinlichkeit sind zudem beachtenswert, weil sie aufzeigen, dass tDCS keine

unabhängigen Effekte hat, sondern immer im Zusammenhang mit der durch die experimentelle Situation bzw. der Aufgabe ausgelösten Aktivität betrachtet werden muss (Bortoletto et al., 2015), insofern also als „Priming“ der Neurone verstanden werden kann (Miniussi & Ruzzoli, 2013). Zudem sei darauf hingewiesen, dass die aktuelle Kritik an der frontalen Asymmetrie als Maß der Persönlichkeit (Kuper et al., 2019) nicht unbedingt gegen die vorliegenden Befunde spricht, da die frontale Asymmetrie häufig im Ruhe-EEG gemessen wird, welches durchaus nicht frei von situationalen Faktoren ist, die das Verhalten auf Grundlage der Persönlichkeit beeinflussen können (Wacker et al., 2013). Vielmehr habe ich versucht, die frontale Asymmetrie während der aktiven Bearbeitung einer Aufgabe zu manipulieren. Entsprechende Befunde deuten darauf hin, dass sich die frontale Asymmetrie im Ruhe-EEG und z. B. während der Bearbeitung einer Aufgabe unterscheiden (Harmon-Jones & Gable, 2018; Kaack et al., 2020). Insgesamt sprechen die Ergebnisse also grundsätzlich für einen Zusammenhang zwischen frontaler Asymmetrie und der Annäherungsmotivation.

In Studie 2 habe ich versucht, die Annäherungsmotivation mittels der Manipulation der DA-Konzentration im MCLDA zu beeinflussen. Hierfür haben die Hälfte der Teilnehmer 200mg Sulpirid und die andere Hälfte der Teilnehmer ein Placebo eingenommen. Die Ergebnisse widersprachen meinen Erwartungen, die Einnahme einer niedrigen Dosis Sulpirids führte zu einer Verringerung der Anstrengungsbereitschaft und somit der Annäherungsmotivation. Dies widerspricht bisherigen Studien, nach denen niedrige Dosierungen Sulpirids mit einer Erhöhung der DA-Konzentration (Tagliamonte et al., 1975; Rankin et al., 2009) und einer generell motivationssteigernden Wirkung assoziiert sind (Serra et al., 1990; Kuroki et al., 1999). Hierfür können verschiedene Erklärungsansätze herangezogen werden. Zunächst könnte die Dosierung zu hoch gewesen sein und tatsächlich eine Verringerung der DA-Konzentration bewirkt haben und somit in Relation zu anderen Studien, welche höhere Dosierungen Sulpirids (>400mg) eingesetzt haben, dennoch vergleichbare Effekte bewirkt haben (Weber et al., 2016, Ojala et al., 2018, Diederen et al., 2017, Kahnt et al., 2015, Eisenegger et al., 2014). Nicht

zuletzt haben frühere Studien auch darauf hingewiesen, dass sowohl exzitatorische als auch inhibitorische Effekte nach der Gabe von Sulpirid nicht unabhängig auftreten, sondern zeitlich versetzt auftreten können (Mueller et al., 2011). Dies könnte bedeuten, dass der Zeitpunkt der Durchführung der EEfRT (ca. 3,5 Stunden nach der Einnahme des Sulpirids) bereits in das Zeitfenster eines inhibitorischen Effekts der Substanz gefallen ist.

Insgesamt konnten dennoch beide Studien zeigen, dass die neurophysiologischen Prozesse, welche mit Annäherungsmotivation assoziiert werden (frontale Asymmetrie, MCLDA), wahrscheinlich in einem kausalen Zusammenhang stehen. Es bedarf natürlich diverser weiterer Studien, welche diese Zusammenhänge erforschen. In Hinblick auf Studie 1 wären dabei z. B. verschiedene technische Settings denkbar, welche entweder andere Positionierungen der Elektroden (z. B. Kathode über dem rechten dlPFC; Vergleich: Bogdanov et al. 2017), andere Stromstärken (z. B. 2 mA; Vergleich: Kesser et al., 2011; Vanderhasselt et al., 2013), oder Stimulationsdauern (Paulus, Antal & Nitsche, 2012) einsetzen. Alle diese Stellschrauben könnten genutzt werden, indem verschiedene Settings gezielt miteinander verglichen werden und Effekte auf der Verhaltensebene so den einzelnen Manipulationen kausal besser zugeschrieben werden können. Ein ähnliches Vorgehen wäre auch in Anlehnung an Studie 2 denkbar. So könnte der Effekt unterschiedlich hoher Sulpirid-Konzentrationen direkt miteinander verglichen werden (Vergleich: Eisenegger et al., 2014), auch unterschiedliche zeitliche Abstände zwischen der Medikamenteneinnahme und der Durchführung einer Verhaltensmessung wären denkbar. Auch dies würde zu einer besseren Überprüfbarkeit der kausalen Zusammenhänge führen.

Limitationen

Trotz sorgfältiger Planung sind Studien 1 und 2 nicht frei von Limitationen. Eine aus meiner Sicht besonders zentrale Einschränkung der Aussagekraft beider Studien ist die mangelnde Überprüfung der tatsächlich bewirkten Effekte auf neurophysiologischer Ebene. Es bleibt unklar, ob die anodale tDCS in Studie 1 und die pharmakologische Manipulation in Studie 2

tatsächlich den erwünschten Effekt erzielt haben, also ob tatsächlich eine stärker linksseitige Aktivierung frontaler Hirnareale eingetreten ist (Studie 1) und sich die DA-Konzentration im MCLDA tatsächlich erhöht hat (Studie 2). Aufgrund der fehlenden Überprüfung bleiben die aktuellen Ergebnisse nur vorläufig und es kann nicht ausgeschlossen werden, dass die Ergebnisse durch andere Effekte entstanden sind. Zwar können aufgrund des Studiendesigns statistische Artefakte bzw. Zufallseffekte bis zu einem gewissen Grad ausgeschlossen werden, dennoch wären z. B. auch andere neuronale Effekte als Ursache für die in beiden Studien gefundenen Effekte denkbar. Sowohl tDCS als auch Sulpirid haben gezeigt, dass ihre Effekte weit über den Cortex gestreut auftreten (Diederen et al., 2017; Romero Lauro et al., 2014). Außerdem übernehmen einzelne Hirnareale häufig nicht nur eine einzige Funktion. Vorstellbar wäre z. B., dass die anodale Stimulation des linken dlPFC einen Effekt auf das Arbeitsgedächtnis (Hill et al., 2016, Trumbo et al., 2016) oder die Risikobereitschaft (Khaleghi et al., 2020) hatte und dadurch das Verhalten beeinflusst wurde. Letztlich können über die genauen Effekte beider Manipulationen auf das Verhalten nur Aussagen getroffen werden, wenn die neurophysiologischen Effekte kontrolliert werden. Ansätze hierzu gibt es in der Forschung reichlich. So ermöglichten Studien, welche tDCS und TMS kombinieren, bereits spannende Einblicke in die Effekte der tDCS. Dabei macht man sich eine bestimmte Eigenschaft der TMS zu nutze. Die Wirkung von TMS wird in der Regel überprüft, indem der motorische Cortex mit steigernder Intensität stimuliert wird, bis eine Intensität erreicht ist, welche ein unwillkürliches Zucken des Daumens bewirkt (Bungert et al., 2017). Setzt man nun zunächst tDCS und dann TMS ein, so konnte gezeigt werden, dass je nach Methode (anodale Stimulation/ kathodale Stimulation) die für den beschriebenen Test via TMS benötigte Intensität größer bzw. kleiner wurde (z. B. Monte-Silva et al., 2010; Romero Lauro et al., 2014; Bashir et al., 2019). Diese Kombination bestätigt einerseits den grundsätzlichen Effekt der tDCS und anderseits eröffnet es für die zukünftige Forschung spannende Möglichkeiten. Durch die Überprüfung der tDCS mittels TMS könnte z. B. einerseits der tatsächliche Effekt der

Stimulation bestimmt werden und andererseits auch eine individuell benötigte Stromstärke bzw. Stimulationsdauer berechnet werden, damit alle Probanden eine vergleichbare Stimulation erhalten. Natürlich ist hier einschränkend zu erwähnen, dass nicht jeder Cortex einen vergleichbar gut überprüfbaren Effekt wie der motorische Cortex aufweist, dennoch könnte dieser Effekt als Referenzwert betrachtet werden, wie es in der Forschung mittels TMS bereits der Fall ist (Bungert et al., 2017). Des Weiteren könnte tDCS auch mit bildgebenden Verfahren wie dem EEG kombiniert werden. Auf diese Weise ließen sich die Effekte der tDCS direkt erfassen (Bergmann et al., 2016).

Auch Studie 2 unterliegt einem vergleichbaren Problem. Die tatsächlichen DA-Konzentrationen im MCLDA konnten nicht untersucht werden. Hierzu könnten einerseits Blutproben (Vergleich: Eisenegger et al., 2014) entnommen werden. Über die DA-Konzentration im Blut könnten indirekt Rückschlüsse über die DA-Konzentration im MCLDA gezogen werden. Anderseits wären auch aufwändigere Verfahren zur Bestimmung der DA-Konzentration im MCLDA denkbar. Neuere Verfahren wie die Positronen-Emissions-Tomographie (PET) erlauben z. B. die Messung der Konzentration dopaminerger Neurone. Vorstellbar wäre hier z. B. eine Kombination dieser Verfahren (Blutprobe / PET), denn DA kann letztlich nur dort aktiv sein, wo auch entsprechende Neurone mit passenden Rezeptoren vorhanden sind. Für die Dichte der dopaminergen Neurone konnte z. B. auch bereits eine interindividuelle Variation nachgewiesen werden, welche ebenfalls einer frontal asymmetrischen Verteilung folgt (Tomer et al., 2008; Tomer et al., 2014).

Neben dieser zentralen Limitation gibt es einige weitere Aspekte, die an dieser Stelle besprochen werden sollten. Einerseits wurden in beiden Studien vorwiegend studentische Stichproben untersucht. Wenngleich viele psychologische Studien ähnlichen Problemen ausgesetzt sind, muss die Einschränkung durch die Stichprobe dennoch erwähnt werden. Generalisierungen auf die Allgemeinheit schließen sich daher grundsätzlich aus und bedürfen weiterer Erforschung. Während in Studie 1 eine überwiegend weibliche Stichprobe untersucht

wurde, wurde in Studie 2 eine rein männliche Stichprobe untersucht, um unerwünschte Nebenwirkungen der pharmakologischen Stimulation zu vermeiden. Trotz der Notwendigkeit der eingeschränkten Stichprobe in Studie 2 ergeben sich dadurch weitere Probleme. Es ist nicht auszuschließen, dass ausbalancierte Stichproben (50% männlich / 50% weiblich) letztlich andere Effekte aufzeigen könnten.

Nicht zuletzt hat auch die EEfRT in Studie 1 einige Schwachpunkte aufgezeigt. Die Rückmeldung einiger Teilnehmer führte uns darauf, dass die unterschiedliche Länge der beiden Aufgaben (leicht: 7 Sekunden / schwer: 21 Sekunden) bei gleichbleibender Gesamtlänge der EEfRT zur Folge hat, dass die Wahl der schweren Aufgabe nicht automatisch einen höheren Gewinn verspricht. Die in Studie 2 eingesetzte Modifikation sollte dieses Problem lösen. Nach Sichtung der Literatur stellten sich jedoch grundsätzliche Fragen zu den Effekten solcher Modifikationen auf die Reliabilität und Validität der EEfRT. Diese Fragen sollten in Studie 3 und 4 beantwortet werden.

6.2 Die Reliabilität und Validität der Messinstrumente

Die Studien 3 und 4 haben die Reliabilität und Validität der beiden Varianten der EEfRT, welche ich zur Erfassung der Anstrengungsbereitschaft als Maß der Annäherungsmotivation verwendet habe, untersucht. Dafür habe ich in Studie 3 beide Aufgaben direkt miteinander verglichen und u.a. diverse Fragebogen zur Validierung verwendet. Studie 4 sollte zusätzlich die Validität der originalen EEfRT in einer bedeutend größeren Stichprobe untersuchen (n = 394), um so auch kleinere Effekte entdecken zu können. Hintergrund waren einerseits die Probleme der originalen EEfRT (z. B. strategisches Vorgehen; Studie 1) und andererseits die komplexen Ergebnisse, welche teilweise meinen Hypothesen widersprachen (Studie 2). Zudem stellte sich beim Studium der Literatur schnell heraus, dass es um die Überprüfung der Reliabilität und Validität der EEfRT eher schlecht bestellt war (siehe Abschnitt 1.3.2). Wie zuvor erwähnt hat fast jede Studie, welche die EEfRT verwendete, kleinere oder größere Modifikationen an der Aufgabe vorgenommen, um diese entweder für die Teilnehmer leichter

zugänglich zu machen (z. B. Yang et al., 2014) oder um die EEfRT an spezielle Forschungsfragen anzupassen (z. B. Byrne & Ghaiumy Anaraky, 2019). So nachvollziehbar all diese Anpassungen auch sein mögen, eine gezielte Überprüfung der Effekte auf das Verhalten der Teilnehmer blieb in der Regel aus. Üblicherweise gaben sich die meisten Autoren damit zufrieden, die Effekte der zentralen Variablen der EEfRT (Belohnungshöhe, Gewinnwahrscheinlichkeit) zu replizieren. Immerhin drei Studien bescheinigten der EEfRT eine zufriedenstellende Reliabilität, darunter Studie 2 (Reddy et al., 2015; Horan et al., 2015; Ohmann et al., 2020).

Studien 3 und 4 konnten diese ausreichende Reliabilität, sowohl für die originale als auch die modifizierte EEfRT, bestätigen. Damit kann die EEfRT insgesamt als ein messgenaues Instrument bezeichnet werden. Dies ist umso erwähnenswerter, da aktuell vermehrt über die mangelhafte Reliabilität vieler behavioraler Messinstrumente diskutiert wird (Dang et al., 2020). Diese mangelhafte Reliabilität wird u.a. dafür verantwortlich gemacht, dass die Korrelationen zwischen selbstberichteter Persönlichkeit und Verhalten, welches mittels behavioraler Messinstrumente erfasst wird, zwischen „nicht vorhanden“ bis „gering“ schwanken (z. B. für Empathie und Risikobereitschaft; Dang et al., 2020). Zudem wurde auf dieses Problem auch im Zuge der Diskussion über die geringe Replizierbarkeit vieler Forschungsergebnisse in der Psychologie hingewiesen (Open Science Collaboration, 2015). Nur messgenaue Instrumente können letztlich auch zur sinnvollen Überprüfung der Validität eingesetzt werden. Für die Reliabilität beider Varianten der EEfRT spricht auch, dass beide Studien vergleichbare Verhaltensmuster in Abhängigkeit der zentralen Variablen der Aufgabe (Belohnungshöhe, Gewinnwahrscheinlichkeit) aufweisen. Überraschend hingegen waren die signifikanten aber insgesamt niedrigen Korrelationen zwischen beiden Aufgaben in Studie 3, welche zwischen .160 und .305 lagen. Aufgrund der hohen theoretischen und konzeptionellen Ähnlichkeit beider Aufgaben hätte man hier durchaus höhere Korrelationen erwarten können, insbesondere da auch für die individuellen motorischen Fähigkeiten kontrolliert wurde.

Vergleicht man diese Werte mit denen, welche von Dang et al. (2020) berichtet werden, erscheinen sie umso überraschender, da in Studie 3 zwei behaviorale Messinstrumente, die beide zur Erfassung der Anstrengungsbereitschaft als Maß der Annäherungsmotivation erstellt wurden, kaum höher korrelierten. Dies zeigt, wie wichtig es ist, auch vermeintlich kleine Modifikationen einer Aufgabe gegen das Original zu testen. Idealerweise sollten Modifikationen an bestehenden Aufgaben nur umgesetzt werden, wenn diese zwingend notwendig erscheinen. Zudem zeigen die niedrigen Korrelationen, dass das Verhalten der Teilnehmer in der EEfRT von deutlich mehr als nur der Annäherungsbereitschaft beeinflusst wird und dass beide Varianten sich in ihren potentiellen Einflussfaktoren erheblich unterscheiden dürften.

Dies wird auch durch die insgesamt schwachen Ergebnisse bzgl. der Validität der beiden Varianten der EEfRT bestätigt. Während in Studie 3 zumindest BAS und antizipatorischer Genuss (TEPS) mit dem Verhalten in der EEfRT korrelierten und dies auch in die erwartete Richtung taten (höhere Ausprägung = mehr Anstrengung), wurden die Effekte in teils völlig anderen Trial–Kategorien gefunden als in früheren Studien (z. B. Geaney et al., 2015). Während dies zumindest noch ansatzweise als Bestätigung der Validität hatte interpretiert werden können, zeigte Studie 4 in einer deutlich größeren Stichprobe keinerlei Zusammenhang zwischen dem Verhalten in der originalen EEfRT und den BIS/BAS–Skalen. Einschränkend muss man hier erwähnen, dass ich in Studie 4 nur die originale EEfRT eingesetzt habe und auch die TEPS nicht zum Einsatz kam, da die Erhebung bereits vor der Erstellung der modifizierten EEfRT und den Erkenntnissen aus den Studien 1 und 2 begann. Insofern kann an dieser Stelle nicht abschließend darüber geurteilt werden, ob die Zusammenhänge nicht zumindest für die modifizierte EEfRT in einer vergleichbar großen Stichprobe Bestand haben könnten. Insgesamt erscheinen die Ergebnisse aber als belastbarer Hinweis für die eingeschränkte Validität der EEfRT. Dies muss nicht unbedingt bedeuten, dass die EEfRT nicht in der Lage ist, Annäherungsmotivation zu messen. Tatsächlich könnte auch die Unterschiedlichkeit der

beteiligten Prozesse bei der Bearbeitung von Selbstberichten und behavioralen Messinstrumenten als Erklärung herangezogen werden (Dang et al., 2020). In diesem Sinne sollte hinterfragt werden, ob eine Korrelation zwischen einem Selbstbericht, welcher häufig aus der Einschätzung des eigenen Verhaltens in einer Vielzahl komplexer Situationen beruht, und der Messung des Verhaltens in einer spezifischen künstlichen Situation überhaupt zu erwarten ist. Vielmehr plädiere ich dafür, dass auch behaviorale Messinstrumente aus unterschiedlichen Situationen bzw. Varianten bestehen sollten, die dann vergleichbar mit einer Fragebogenskala kombiniert werden können. Vergleichbar mit der Konstruktion eines Fragebogens könnten solche Tests, die am niedrigsten mit der Gesamtskala korrelieren, entfernt werden. Die EEfRT kann aufgrund ihrer guten Reliabilität hierfür durchaus als Basis genutzt werden. So konnten bereits diverse Studien zeigen, dass hier verschiedene Varianten der Belohnungen (Racine et al., 2018), als auch der Bestrafungen (Byrne & Ghaiumy Anaraky, 2019), oder des Settings (Gilman et al., 2015) denkbar sind. Meiner Auffassung nach würde die Kombination verschiedener Varianten auch die Validität der Aufgabe erhöhen, da Annäherungsmotivation im Alltag viel mehr ist als „nur“ die Bereitschaft, sich für Geld physisch anzustrengen. Andersherum könnte auch die Erfassung der Persönlichkeit mit konkretem Bezug zur aktuellen Situation dabei helfen, die bestehende Diskrepanz in der Persönlichkeitsforschung zwischen Selbstberichten und Verhalten zu überbrücken (Horstmann & Ziegler, 2020). Dies könnte z. B. mittels der „Situation Five“ geschehen, darunter zählen Ziegler et al. (2019) u.a. die kognitive Belastung und einen Mangel an Stimuli.

6.3 Schlussfolgerung

Die von mir durchgeführten Studien konnten einerseits die Reliabilität der beiden Varianten der EEfRT und anderseits den kausalen Zusammenhang zwischen dem Verhalten in der EEfRT und zwei verschiedener neurophysiologischer Marker (frontale Asymmetrie, DA-Konzentration im MCLDA) grundsätzlich bestätigen. Somit kann die EEfRT durchaus als Grundlage für die weitere Erforschung der Annäherungsmotivation empfohlen werden. Durch meine Forschung haben sich dabei jedoch diverse neue Fragen aufgetan. Zunächst sollte es das Ziel zukünftiger Forschung sein, die Reliabilität und Validität der EEfRT weiter zu ergründen. Die Ergebnisse meiner Studien deuten darauf hin, dass es dabei notwendig sein dürfte, die Variabilität des abgefragten Verhaltens in einem Persönlichkeitsfragebogen auch bei der behavioralen Messung der Persönlichkeit zu berücksichtigen. Rufen wir uns an dieser Stelle noch einmal meine zu Beginn dieser Dissertation genannten Beispiele in Erinnerung (der Besuch beim Bäcker, das Schreiben einer Doktorarbeit), so wird schnell deutlich, dass die Komplexität kleiner und großer alltäglicher Entscheidungen nicht durch die Messung der Annäherungsmotivation mittels einer einzigen Aufgabe im Labor erfasst werden kann. Demnach könnte der Einsatz eines Sets verschiedener Aufgaben, die das gemeinsame Konstrukt „Annäherungsmotivation“ messen, vielversprechender sein. Ähnliches ist z. B. in der Intelligenzforschung seit vielen Jahrzenten der gängige Standard für die Entwicklung verschiedener Testbatterien (Kubinger, 2019). Warum sollten wir der Annäherungsmotivation weniger Komplexität zusprechen?

In Bezug auf die neurophysiologischen Marker sollte es das Ziel zukünftiger Forschung sein, die durch eine Manipulation bewirkten Änderungen direkt auf neurophysiologischer Ebene zu messen. Andernfalls bleiben die Ergebnisse der Forschung (so wie aus Studie 1 und 2) nur eingeschränkt aussagekräftig. Die Kombination verschiedener Verfahren, z. B. tDCS und TMS (Monte-Silva et al., 2010; Romero Lauro et al., 2014; Bashir et al., 2019) könnten hier spannende neue Erkenntnisse liefern. Im Licht der aktuellen Krise in der psychologischen

Forschung aufgrund der mangelhaften Replizierbarkeit bestehender Ergebnisse (Open Science Collaboration, 2015) möchte ich an dieser Stelle abschließend dafür plädieren, die Details der Studiendurchführung (und damit meine ich auch technische Details) stets mit größtmöglicher Präzision zu nennen und so für andere Forscher nachvollziehbar zu machen. Idealerweise sollten daraus Leitfäden und Standards entstehen, die z. B. Stimulationsstärke, Stimulationsdauer und Anbringung der Elektroden (tDCS) oder die Dosierung und den zeitlichen Abstand bis zur Verhaltensmessung (Sulpirid) standardisieren. Andernfalls läuft die psychologische Forschung weiterhin Gefahr, ihre Forschungsergebnisse trotz großer Anstrengungen (wie z. B. durch die Preregistration der Hypothesen und größerer Stichproben) nicht replizieren zu können.

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Anhang

A: Studie 1: Left frontal anodal tDCS increases approach motivation depending on reward attributes.

Ohmann, H. A., Kuper, N., & Wacker, J. (2018). Left frontal anodal tDCS increases approach motivation depending on reward attributes. *Neuropsychologia, 119,* 417–423. https://doi.org/10.1016/j.neuropsychologia.2018.09.002

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Left frontal anodal tDCS increases approach motivation depending on reward attributes

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ABSTRACT

Background: A growing body of literature indicates a correlation between asymmetrical activity of frontal brain sites and approach vs. withdrawal motivation. Yet the causal status of this relationship is presently unclear. Here we examined the effect of anodal tDCS applied over the left dorsolateral prefrontal cortex (dlPFC) on approach motivation, operationalized as effort allocation during the Effort-Expenditure for Reward Task (EEfRT).

Hypothesis: We expected left frontal anodal transcranial direct current simulation (tDCS) to increase participants' willingness to allocate more effort during the EEfRT. Based on previous research, we expected this effect to be strongest on trials with low probability of reward attainment.

Methods: 60 right-handed neurologically and psychologically healthy participants (63% female) aged 18–35 were tested in a counterbalanced within-subject design. Participants were invited to our lab twice to complete two 15-min blocks of the EEfRT on each study day, randomly assigned to either an anodal tDCS or a SHAM condition.

Results: No main effect of stimulation condition was found, however the interactions of stimulation condition and both probability of reward attainment and reward magnitude reached significance. These interactions indicated that left frontal anodal tDCS specifically increased the percentage of hard task choices (HTC) in trials with low probability of reward attainment and in trials with high reward magnitude.

Discussion: The observation of an increasing effect of left frontal anodal tDCS on effort expenditure for reward as indicated by HTC supports the idea of a causal relationship between asymmetric activity of frontal brain sites and approach motivation and hints at moderating effects of task-features on the effects of tDCS.

1. Introduction

Our decisions are based on motivational processes, which evaluate potential benefit or harm and can therefore be described as the main drives of human behavior (Lazarus, 1991a, 1991b). Decision-making is a result of these motivational processes leading to a motivational direction – we either decide to go toward or to go away (approach or withdraw) from something, which is often but not necessarily a specific stimulus (Harmon-Jones and Gable, 2017). These two motivational directions can be described as approach motivation and withdrawal motivation and have been theoretically associated with two neurophysiologically differentiable systems including left and right frontal cortical areas, respectively (Davidson, 1992). This theoretical proposition is supported by studies of asymmetrical EEG alpha activity at frontal brain sites during the experience and expression of emotions and motivation: Stronger relative left frontal activity is related to approach motivation and stronger relative right frontal activity to withdrawal motivation (Harmon-Jones and Gable, 2017; Rutherford and Lindell, 2011). Frontal asymmetry has also been linked to reward processing (Gorka et al., 2015; Miller and Tomarken, 2001; Sobotka et al., 1992), dopaminergic activity as well as personality traits connected to approach behavior (Wacker et al., 2013; Wacker, 2018) indicating that frontal asymmetric activity is connected to the evaluation as well as the approach to/withdrawal from (possibly) rewarding/punishing stimuli. Although these results are intriguing, they are based on correlations and little is known about the causal relation of frontal asymmetry and motivational direction (Kelley et al., 2017). A promising tool to manipulate frontal neural activity and thus presumably motivational direction is transcranial direct current stimulation (tDCS).[1] tDCS alters the neural polarization on a sub-threshold – level, which in turn

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[1] Abbreviations: dlPFC: dorsolateral prefrontal cortex EEfRT: Effort-Expenditure for Reward Task tDCS: transcranial direct current stimulation HTC: hard task choices GEE: Generalized Estimating Equation.

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changes the excitability of the neurons (Bikson et al., 2012). Anodal stimulation leads to a higher neural excitability, while cathodal stimulation leads to a lower neural excitability (Paulus et al., 2012). So far, only a small proportion of studies in the field of brain stimulation applied tDCS over frontal brain areas, of which many focused on working memory (Hill et al., 2016). In terms of manipulating motivation using tDCS, the literature so far is rather inconsistent with some studies supporting the frontal asymmetry model of motivation (Chrysikou et al., 2016; Hortensius et al., 2012; Kelley et al., 2013, 2015; Riva et al., 2015) and others failing to do so (Fecteau et al., 2007; Russo et al., 2017; Shen et al., 2016; Soutschek et al., 2018; Ye et al., 2015). There are at least five factors, which might explain this inconsistency and should be taken into account when interpreting results in this field of research: First, the neurophysiological effects of prefrontal tDCS are relatively diverse and not yet fully understood (Wörsching et al., 2016). Second, the effects of tDCS stimulation may interact with task-induced brain activity (Bortoletto et al., 2015). Third, cathodal stimulation has generally shown less consistent results than anodal stimulation (Dedoncker et al., 2016). Fourth, tDCS stimulation can be applied using diverse stimulation settings (e.g., different electrode sizes, different intensities, different electrode placements, and different time spans). It is highly likely that all of these parameters change the effect of tDCS in some way. Fifth, the paradigms used in the aforementioned studies operationalized motivation in fundamentally different ways, using completely different outcome measures. To counteract as many of these factors as possible, we focused on anodal stimulation, took the interaction of stimulation and task parameters into account, focused on a tDCS stimulations setting which has been used to stimulate the dlPFC in various previous studies and relied on a well-established task, which is based on the universal and generalized reinforcing effect of money (Skinner, 1968), the Effort-Expenditure for Reward Task (EEfRT) (Treadway et al., 2009). The EEfRT is a decision-making task measuring individuals' reward motivation. The EEfRT is based on the premise that reward motivation can be described as a tendency of an organism to choose between opportunities that vary in both reward and cost. "Costs can include effort required (effort costs) and likelihood of failing to obtain the reward (probability costs)" (Wardle et al., 2012, p. 1). Participants choose between an easy task (little effort needed) with a small reward and a hard task (greater effort needed) with a variable larger reward and individuals' willingness to increase effort expenditure for rewards is then taken as an index of reward/approach motivation. The validity of this task as an index of approach motivation is, for instance, supported by a correlation between the percentage of hard task choices (HTC) in trials with a low probability of reward attainment and self-reported trait approach motivation (Geaney et al., 2015) as well as stronger relative left frontal brain activity as measured via resting EEG (Hughes et al., 2015). Furthermore, psychological disorders associated with impaired motivation like schizophrenia (Barch et al., 2014; Fervaha et al., 2013; McCarthy et al., 2016) and depression (Treadway et al., 2012; Yang et al., 2014) have been associated with a decreased percentage of HTC. Based on these encouraging validity findings, the EEfRT seems well-suited as an objective index of reward/approach motivation. In the present study, we therefore provide an initial test of the effects of anodal tDCS over the left dorsolateral prefrontal cortex (dlPFC) vs. SHAM stimulation on the percentage of HTC in the EEfRT. In addition, we conducted a number of additional validity checks on the EEfRT task.

1.1. Hypotheses

1.1.1. Stimulation effects

We expected an increase in overall HTC for tDCS stimulation of the left dlPFC compared to sham stimulation. Furthermore, in line with previous research (Geaney et al., 2015; Hughes et al., 2015), we expected the effect of tDCS stimulation on HTC to be strongest in trials with low probability of reward attainment. We also expected an interaction between reward magnitude and tDCS since different reward magnitudes within the EEfRT have been shown to lead to different levels of activity in the human reward circuitry (Huang et al., 2016). This endogenous activity of the behavioral approach system should interact with the exogenous effects of tDCS.

1.1.2. EEfRT – task validity

Especially, because we were unaware of prior work employing the original EEfRT (Treadway et al., 2009) in a repeated measurements design, we tested several hypotheses regarding the validity of the task. In line with previous research, we expected the reward attributes (reward magnitude and probability of reward attainment) to be positive predictors of the number of HTC, whereas we expected trial number within task blocks (i.e., an indicator of fatigue) to be a negative predictor of HTC. We only tested right-handed participants, who typically show worse motoric performance with their left hand on finger tapping tests (Hervé et al., 2005). Therefore, we expected the factor hand to be a significant predictor of HTC, as participants should make fewer HTC with their left hand due to the increased effort requirements.

2. Methods

2.1. Participants

We recruited 60 right-handed neurologically and psychologically healthy participants (63% female) aged 18–35 (M = 24.82; SD = 4.13) using online notice boards and advertising via black board postings at the University of Hamburg, Germany. An a-priori power analysis was conducted via G-Power (Version 3.1). Based on previously reported effect sizes of anodal tDCS stimulation (i.e. Riva et al., 2015), we chose a small expected effect size (d = 0.35) for our within-subject design. G-Power calculated a minimum sample size of 52 participants to be required for an 80% probability of finding a significant effect (alpha = 0.05). Participants received monetary compensation and were told that they can gain additional money based on their collected rewards from the EEfRT (5% of the sum of monetary rewards shown on the screen). At the end of the study, we revealed to all participants that the additional money was fixed at 10€ (which was generally higher than the rewards collected while playing) to ensure equity. The study has been approved by the Human Research Ethics Committee of The University of Hamburg.

2.2. Procedure

Participants were invited to the lab twice with at least 7 days between both sessions. Before starting, participants were randomly assigned to one of 4 study conditions. Between the 4 study conditions, the order of tDCS stimulation (sham/anodal) and the order of hand (left/right) used in the first and second block per session varied systematically. Each participant received both stimulation conditions and both hand orders by counterbalancing between both study days. On the first day of testing each participant completed the consent form, a demographic data survey and several questionnaires. Afterwards, participants were stimulated for 20 min using tDCS either with real or SHAM (= placebo) stimulation, while completing the practice trials (5 min) and the first EEfRT block (15 min), followed by the second EEfRT block (15 min) completed without tDCS stimulation. This time frame is well within the range of tDCS after effects. Depending on stimulation setting and targeted region, the after effect of tDCS stimulation varies and ranges between 1 and 5 h for frontal brain areas (Reinhart et al., 2017). On study day two, participants followed the same procedure as on study day one, receiving the other stimulation condition and EEfRT block order according to their study condition.

2.3. tDCS

A battery-driven, constant current stimulator (DC Stimulator Plus; NeuroConn, Ilmenau, Germany), which transfers direct current via a pair of saline-soaked sponge electrodes (7 cm × 5 cm; 35 cm^2), was used in this study. This tDCS stimulator allows for SHAM – stimulation, which is a placebo stimulation described as indistinguishable from real stimulation. Stimulation starts by entering a pre-assigned code, so that neither participants nor test administrators are aware of the actual stimulation condition, which allows for a double-blinded administration. Nonetheless, as some studies hint at incomplete blinding using tDCS possibly due to increased skin sensations (Horvath, 2015), we asked participants to guess on which day they received anodal ("real") stimulation at the end of the study. The anode was placed above the left dlPFC at F3 position using an EEG cap (according to the international 10–20 system; Jurcak et al., 2007) and the cathode above the right supraorbital region. We chose the dlPFC as a target region because it is a central structure of the human brain network reflecting approach and avoidance motivation (Spielberg et al., 2012; Volkow et al., 2017) and studies aiming at manipulating approach motivation via tDCS often target the dlPFC, which they do so by applying tDCS stimulation over the F3 and/or F4 EEG positions (Kelley et al., 2017). This is in line with a broad range of EEG studies which typically measure frontal asymmetry as the difference in neural activity of the frontal brain regions underneath electrode positions F3 and F4 (Reznik and Allen, 2018). Studies trying to stimulate the frontal cortex via tDCS often place the non-target electrode above the supraorbital area of the opposite hemisphere due to the increased skull thickness and reduced current. (Riva et al., 2015). Each tDCS condition was been applied for 20 min (15 s ramp in and 15 s ramp out) at 1 mA stimulation intensity. Impedance was automatically controlled by the tDCS stimulator, aborting stimulation above 55 kΩ.

2.4. EEfRT

We used a slightly adapted and translated (German) version of the EEfRT (Treadway et al., 2009), which was programmed using Presentation software 17.1 (Neurobehavioral Systems Inc., San Francisco). Every participant completed four 15-min blocks (two on each study day) of the EEfRT instead of one 20-min block as in the original version. Participants were instructed to complete one block with their right hand and one block with their left hand on each study day in a randomized order. This was done to rule out possible interactions between lateralized motor activity and tDCS stimulation. Participants were instructed to win as much virtual money as possible throughout each 15-min block. In short, participants need to choose between an easy, low-reward task and a hard, high-reward task in every trial (see Fig. 1 for a schematic illustration). The reward for the easy task is fixed to 1 € while the reward for the hard task is variable (ranging between 1.21 € and 4.30 €). To further manipulate the value of each reward, the probability of reward attainment also varies [either 12% (low), 50% (middle) or 88% (high)], which is presented at the start of each trial alongside the reward values. The easy task requires participants to press the space button 30 times in 7 s with their index finger. The hard task requires participants to press the space button 100 times in 21 s with their pinkie finger. While pressing the spacebar, a visually presented white bar gradually fills up with red color. After each trial, the participants are informed about the amount of money they won during the trial. The order of trials, as well as the probability of reward attainment and the reward magnitudes are not randomized between participants, but pre-assigned for each trial. This is done to rule out random feedback differences between participants. Each block consisted of a different predetermined order of the same individual trials. This was done to avoid learning effects, as participants may remember the order of trials and the related feedback.

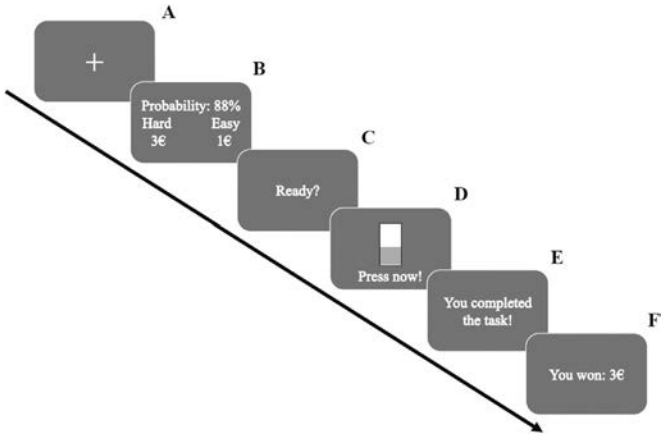

Fig. 1. Schematic illustration of one trial on the EEfRT. A fixation cross (1 s) is followed by a screen showing probability of reward attainment and reward magnitude for the easy and hard task, lasting until the participant made a choice which task to complete but no longer than 5 s. Then, after a ready – screen (1 s) main screen for the trial showing a red bar that fills with each button press is presented until the task is completed or until the trial time is over. Finally, task completion is signaled (2 s) and a feedback screen shows the amount of money won (2 s).

2.5. Data analysis

Aggregated data were further analyzed using the SPSS 22.0 software (Chicago, IL, USA). Effects on the EEfRT choice behavior were analyzed using Generalized Estimating Equation (GEE) models, a generalized regression technique able to model dichotomous outcome variables with correlated residuals (e.g. nested within a single participant) using a link function (Liang et al., 1986; Zeger and Liang, 1986). The dependent measure is HTC, modeled using a logistic link function. The models were fitted using an exchangeable working correlation matrix. All GEE models included the factors day, block, trial number, hand, probability (categorical), reward magnitude and the interaction of probability × reward magnitude (sometimes referred to as "expected value"). Separate models were computed to test basic predictors of HTC, the effects of tDCS stimulation condition (anodal/SHAM) on HTC, as well as interactions between tDCS stimulation condition and reward attributes (reward magnitude and probability of reward attainment).

3. Results

3.1. EEfRT – task validity

Across both study days, participants on average completed 194 trials (sd = 23.23, range = 145–242), with a success rate of 98.16%, (sd = 3.06). Participants completed easy trials with a success rate of 99.13% (sd = 2.43) and hard trials with a success rate of 96.95% (sd = 4.81), success rates of both conditions differed significantly ($t(58) = 4.45$, $p > .001$). Authors of previous studies decided to focus on analyzing the minimum number of trials all participants completed to increase consistency, e.g. Geaney et al., 2015. We decided to include all trials because time-dependent effects of tDCS might be overlooked by excluding a variable number of trials (and therefore a variable amount of time) for each participant. Participants chose the hard task in 46.26% of all trials (sd = 19.98, range = 19.16–100%). Overall, six GEE models were computed to test the validity of the EEfRT (see Table 1, GEE Model 1–6). GEE model 1 examined main effects of task-dependent variables (reward magnitude, probability of reward attainment & trial number) as well as two variables unique to our study (block and hand) on HTC. In line with previous studies, significant positive main effects were found for reward magnitude and probability and a significant negative main effect was found for trial number,

Table 1
GEE models for basic predictors of hard-task choices (EEfRT).

Effect	β	se	χ^2	p
Model 1				
Reward Magnitude	0.45	0.07	47.56	< **.001**
Probability 50%[a]	1.54	0.16	94.55	< **.001**
Probability 88%[a]	3.23	0.28	131.16	< **.001**
Probability 50%[a] × Reward Magnitude	0.52	0.07	48.25	< **.001**
Probability 88%[a] × Reward Magnitude	1.32	0.18	52.14	< **.001**
Hand	0.51	0.07	54.60	< **.001**
Trial	− 0.39	0.09	20.50	< **.001**
Block	− 0.07	0.06	1.49	.222
Model 2				
Hand × Reward Magnitude	0.08	0.06	1.78	.182
Model 3				
Hand × Probability 50%[a]	0.14	0.10	1.94	.164
Hand × Probability 88%[a]	0.22	0.13	2.78	.095
Model 4				
Block × Reward Magnitude	− 0.02	0.05	0.21	.649
Model 5				
Block × Probability 50%[a]	0.16	0.10	2.44	.140
Block × Probability 88%[a]	0.24	0.16	2.18	.119
Model 6				
Study Day	0.05	0.10	0.21	.645

Note. All models included probability (categorical), reward magnitude, trial number, block and hand as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a] Estimates were computed in relation to the low (12%) reward probability level, the parameters for which are therefore redundant.

Table 2
GEE models of tDCS condition (anodal VS SHAM) on hard-task choices (EEfRT).

Effect	β	se	χ^2	p
Model 7				
tDCS Condition	0.05	0.10	0.27	.603
Model 8				
tDCS Condition	0.06	0.10	0.38	.540
tDCS Condition × Reward Magnitude	0.15	0.06	6.23	**.013**
Model 9				
tDCS Condition	0.19	0.14	1.96	.162
tDCS Condition × Probability 50%[a]	− 0.04	0.15	0.07	.791
tDCS Condition × Probability 88%[a]	− 0.45	0.21	4.60	**.032**
Model 10				
tDCS Condition	− 0.11	0.13	0.65	.421
tDCS Condition × Block	0.11	0.15	0.59	.442
Model 11				
tDCS Condition	0.43	0.53	0.66	.418
tDCS Condition × Study Day	− 0.95	1.05	0.82	.365
Model 12				
tDCS Condition	0.35	0.53	0.43	.513
tDCS Condition × Block	0.17	0.21	0.66	.417
tDCS Condition × Study Day	− 0.92	1.02	0.82	.366
tDCS Condition × Block × Study Day	− 0.08	0.23	0.11	.735

Note. All models included probability (categorical), reward magnitude, trial number, block and hand as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a] Estimates were computed in relation to the low (12%) reward probability level, the parameters for which are therefore redundant.

indicating that all three factors were predictors of HTC (all ps < .01). The factor block did not reach significance (β = -0.07, $\chi^2(1) = 1.49$, p = .222), indicating that there were no appreciable differences in HTC between blocks within study days. The factor hand reached significance, indicating that participants, as expected, made more HTC on blocks they completed with their right hand. Neither the interaction of hand and reward, nor the interaction of hand and probability was significant (see Table 1, GEE models 2 and 3).

GEE models 4 and 5 were computed to analyze the interaction of the factor block with reward magnitude and probability. Neither the interaction of block and reward magnitude (β = -0.02, $\chi^2(1) = 0.21$, p = .649) nor the interaction of block and probability (low vs. medium probability: β = 0.16, $\chi^2(1) = 2.44$, p = .140/low vs. high probability: β = 0.24, $\chi^2(1) = 2.18$, p = .119) reached significance, indicating that block did not moderate the effects of probability and reward. GEE model 6 revealed that the factor study day did not reach significance (β = 0.05, $\chi^2(1) = 0.21$, p = .645), indicating that participants did not differ in their number of HTC between study days.

3.2. tDCS effects

Overall, three GEE models were computed to test the effects of anodal left frontal tDCS stimulation on HTC (see Table 2, GEE Model 7–9). In model 7, we tested the main effect of tDCS condition (anodal VS SHAM) on HTC, which was not significant (β = 0.05, $\chi^2(1) = 0.27$, p = .603). In model 8 we analyzed the interaction of tDCS condition (anodal VS SHAM) with reward magnitude and found that the effect of anodal tDCS on HTCs was moderated by reward magnitude such that the positive effect of active tDCS linearly increased with reward magnitude (β = 0.15, $\chi^2(1) = 6.23$, p = .013). Post hoc analyses using reward magnitude as a categorical variable when comparing low vs. high reward trials revealed a significant difference, β = 0.40, $\chi^2(1) = 6.87$, p = .027. When comparing medium vs. high reward as well as low VS medium trials, no significant difference was found, β = 0.14, $\chi^2(1) = 1.50$, p = .221 and β = 0.26, $\chi^2(1) = 4.89$, p = .081, respectively. In model 9, we analyzed the interaction of tDCS condition (anodal VS SHAM) and probability of reward attainment and found that the effect of anodal tDCS on HTC was more positive for low probability trials than for high probability trials (β = -0.45, $\chi^2(1) = 4.60$, p = .032), while no significant difference was found when comparing low probability trials to medium probability trials (β = -0.04, $\chi^2(1) = 0.07$, p = .791).

3.3. Post-hoc control analyses

As we cannot exclude the possibility that anodal stimulation may have affected participants who received anodal stimulation on day 1 (as compared to day 2) differently, we computed three additional post-hoc GEE models including task repetition factors “block” and “study day” and tDCS condition (see Table 2, GEE Model 10–12) to test for possible carry – over effects. None of these three models revealed a significant interaction between task repetition factors and tDCS condition. Thus, the order of tDCS stimulation did not change choice behavior throughout task repetition.

At the end of study day two 40 out of all 60 participants guessed correctly on which day they received the anodal (“real”) stimulation (VS SHAM stimulation), which equals 66,67% and is significantly above the 50% - chance level (t(59) = 2.72, p = .009). Therefore, we added the factor “Guessed Correctly” to three post-hoc GEE models. There was neither a significant main effect nor any significant interaction with stimulation condition and task parameters (see Table 3, GEE Model 13–15). Thus, participants who correctly guessed their stimulation condition did not differ in their HTC and their stimulation effects.

Furthermore, at the end of study day two we asked participants in an unstructured and open manner about their strategies while playing the EEfRT. Descriptively, out of 60 participants 23 reported to have based their choices on concrete “threshold” – strategies (e.g. choosing the hard task only in trials with a reward magnitude higher than 2,50 €). To control for a possible confoundation of our results, we removed those 23 participants from analyses. However, after reanalyzing the data without these participants the stimulation effects were still present.

4. Discussion

In the present study, we examined the effect of anodal tDCS over the left dlPFC on approach motivation, operationalized as effort

Table 3
GEE models of "guessed correctly" (VS "Guessed Incorrectly") on hard-task choices (EEfRT).

Effect	β	se	χ^2	p
Model 13				
Guessed Correctly	− 0.64	0.68	0.89	.344
Guessed Correctly × tDCS Condition	− 0.08	0.23	0.13	.719
Model 14				
Guessed Correctly	0.37	0.44	0.57	.449
Guessed Correctly × tDCS Condition	0.29	0.33	0.75	.386
Guessed Correctly × tDCS Condition × Reward Magnitude	− 0.28	0.19	2.14	.143
Model 15				
Guessed Correctly	− 0.28	0.68	0.16	.686
Guessed Correctly × tDCS Condition	− 0.17	0.29	0.32	.570
Guessed Correctly × tDCS Condition × Probability 50%[a]	0.00	0.27	0.00	.999
Guessed Correctly × tDCS Condition × Probability 88%[a]	0.27	0.38	0.49	.482

Note. All models included probability (categorical), reward magnitude, trial number, block and hand as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a] Estimates were computed in relation to the low (12%) reward probability level, the parameters for which are therefore redundant.

expenditure during the EEfRT (Treadway et al., 2009). Whereas no main effect of stimulation condition was found, the interactions of stimulation and both reward attributes revealed that anodal tDCS increased effort expenditure for both trials with low probability of reward attainment and high reward magnitude. This is in line with previous studies indicating that effort expenditure in low probability trials correlates with higher trait approach motivation (Geaney et al., 2015) and increased left frontal brain activity (Hughes et al., 2015). While to our knowledge the aspect of reward magnitude in the EEfRT was not related to any measure of approach motivation in previous studies e.g. Geaney et al., 2015, the relative increase of effort expenditure for trials with high reward magnitude in our study, hints at the possible importance of this factor. As noted before different reward magnitudes within the EEfRT led to different levels of activity in the human reward circuitry (Huang et al., 2016). It is likely that these different endogenous activity levels interacted with the exogenous effects of tDCS in our study, leading to the observed differences in behavior.

Taken together the absence of a main effect of stimulation condition and the presence of interactions between stimulation condition and both reward attributes support the notion that tDCS stimulation may interact with task-induced brain activity and does not induce behavioral effects per se (Bortoletto et al., 2015). Instead, tDCS stimulation should be understood as "priming" of neurons (Miniussi and Ruzzoli, 2013). This may also explain why tDCS-based treatments (e.g. targeting depression), which often use frontal stimulation setups comparable to the one we used in this study, so far produced weak effects at best (Loo et al., 2018; Palm et al., 2016). Most treatments rely solely on the application of tDCS without introducing any further input to the patients' "primed" neurons. Therefore, futures studies should always examine the interaction of tDCS application and task parameters. Regarding tDCS-based treatments of depression, future studies may increase the effectiveness of treatments by combining tDCS-application and conventional treatments.

Furthermore, we successfully introduced a retest-design to the original EEfRT (Treadway et al., 2009), indicating that this task can be used in retest-design studies. Whereas our right-handed showed more HTC when reacting with their right vs. their left hand, the factor reaction hand did not interact with reward attributes, indicating that the EEfRT shows robust effects independent of reaction hand.

Putting our results into a broader context, anodal tDCS stimulation over the left dlPFC has so far been shown to increase approach motivation in different laboratory situations eliciting different approach related emotions. Based on correlational data by Harmon-Jones et al. (2009), which indicates that social exclusion leads to increased jealousy, Kelley et al. (2015) were able to show that anodal stimulation of the left dlPFC increased jealousy reaction after social exclusion in a cyberball paradigm compared to anodal stimulation of the right dlPFC or SHAM stimulation. Hortensius et al. (2012) were able to show that anodal tDCS stimulation of the left dlPFC increased the aggressive reaction of participants after insulting feedback, but not after anodal tDCS stimulation of the right dlPFC or SHAM stimulation. tDCS might therefore be a promising tool for investigating and manipulating different approach related behaviors. However, as mentioned above, comparability of different tDCS studies is hampered by many cofounding factors and other tDCS studies failed to support the model of frontal asymmetry (e.g. Fecteau et al., 2007; Russo et al., 2017; Shen et al., 2016; Soutschek et al., 2018; Ye et al., 2015).

Although we tried to rule out many of those factors which may have led to the inconsistent results in previous tDCS studies examining the relationship of frontal asymmetry and manipulation of motivation, there are still some limitations to our study. First, as mentioned in the introduction, the effects of frontal tDCS are still poorly understood (Wörsching et al., 2016). Thus, the assumption that anodal left frontal tDCS actually changed frontal asymmetric brain activity in our study cannot be examined directly, although preliminary evidence indicates that the setup we used does change frontal alpha and beta activity (Maeoka et al., 2012). Future studies should combine tDCS and task EEG measurements (bearing in mind that resting EEG may not be a suitable measure, as the influence of task-induced brain activity might be needed to trigger stimulation effects).

Second, our study introduced only one anodal stimulation condition and one SHAM condition. Because cathodal stimulation typically shows less consistent results it seems reasonable to focus on anodal stimulation settings at this point (Dedoncker et al., 2016). Thus, in future work it would be interesting to test whether anodal tDCS over the right dlPFC leads to completely opposite effects compared to anodal stimulation over the left dlPFC as the models of frontal asymmetry and motivation would suggest. However, the considerable variability in tDCS parameters (duration of stimulation, electrode size, electrode placement, etc.) limits generalizability of individual studies. For example, Soutschek et al. (2018) stimulated the right frontopolar PFC via tDCS and found increased reward motivation after anodal stimulation. Although these results are contradictory to what one would expect according to the model of frontal asymmetry, comparisons with our own findings are hampered by various methodological differences, both on tDCS level (e.g. targeted regions were frontopolar PFC and vertex – compared to dorsolateral PFC and supraorbital area in our study) and on the level of measuring reward motivation (e.g. effort had to be invested only once at the end of each study condition – as compared to each trial in our study). As illustrated with this example, a careful description and systematic comparison of the various methodological variants will be essential in better understanding the boundary conditions for specific effects of tDCS on neural activity.

Third, while the EEfRT has been shown to be related to effort allocation and approach motivation, participants' choice pattern might at least partly be explainable by other factors. As reported above out of 60 participants 23 reported to have based their choices on concrete "threshold" – strategies, which are based on the premise that the hard task lasts about three times as long as the easy task (21 vs. 7 s). Choosing the hard task might therefore be a disadvantageous choice in trials with low reward magnitudes or low probabilities of reward attainment. Although our post-hoc control analyses still revealed significant stimulation effects after removing those participants, this adds another possibly confounding factor. Fourth, 66,67% of all participants were able to guess which tDCS condition was "real" (anodal) and which one was the placebo (SHAM). Our statistical control models show that correctly guessing the stimulation conditions did not change

participants' choice behavior nor did it alter the stimulation effects, but it still remains a serious concern for tDCS blinding procedures in general.

Therefore, future studies should counteract these limitations by (1) systematically asking participants about their strategies while playing the EEfRT and/or (2) optimizing the EEfRT, such that the only valid strategy for participants to increase their rewards is to increase their effort allocation. (3) Future studies should also help establishing standards regarding tDCS settings for stimulation of specific target regions as suggested by Reinhart et al. (2017). We encourage future studies to use our settings when stimulating the left dlPFC and to only systematically change single parameters. (4) As insufficient tDCS blinding seems to be an overlooked issue (Horvath, 2015), future studies should always assess participants' perception of stimulation and likewise add statistical control models. Beyond statistical control, tDCS blinding could be improved by e.g. expanding the time participants are mounted with the electrodes, so that participants are not aware of the point of time when stimulation begins and might be less focused on their skin sensations.

4.1. Conclusion

The current data suggest that application of anodal tDCS stimulation over the left dlPFC increases participants approach motivation, as measured via effort allocation during the EEfRT specifically when large rewards are at stake and/or rewards are unlikely. These results support the view of tDCS stimulation as a "priming" of neurons (Miniussi and Ruzzoli, 2013) so that stimulation effects may only be measurable when task-induced brain activity interacts with it. Furthermore, our study supports the idea of a causal relationship between asymmetric activity of frontal brain sites and motivation. Future research is needed to test different stimulation settings, to directly analyze changes in brain activity, to analyze the influence of participants' individual strategies while playing the EEfRT and to optimize blinding procedures.

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A low dosage of the dopamine D2-receptor antagonist sulpiride affects effort allocation for reward regardless of trait extraversion

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Abstract

Dopamine (DA) is known to be involved in various aspects of reward processing and goal-directed behavior. The present preregistered study aims at directly accessing the causal influence of DA activity on reward motivation in humans, while also accounting for trait extraversion. Therefore, we examined the effect of a single dose of the DA D2 receptor antagonist sulpiride (200 mg) on effort allocation in a modified version of the Effort-Expenditure for Reward Task (EEfRT). Based on its presumably DA increasing action, we expected the low dose of sulpiride to increase participants' willingness to allocate effort during the modified EEfRT relative to placebo, especially in trials with low probability of reward attainment. Further, we expected a moderating effect of trait extraversion on the effects of sulpiride. Two hundred and three healthy male participants were tested in a randomized, double-blind between-subjects design. Contrary to our expectations, sulpiride reduced the average number of clicks within the modified EEfRT and did not interact with reward attributes, suggesting a more global and not reward-specific effect of sulpiride. Furthermore, trait extraversion did not moderate the effect of sulpiride. Our results provide initial support for the validity of the modified version of the EEfRT, suggesting a possible inhibiting effect of a low dose of sulpiride on approach motivation regardless of trait extraversion. However, given the mixed pattern of findings and the possible confounding role of motoric abilities, further studies examining these effects are clearly warranted.

Deciding to go for a possible reward requires evaluating its positive and negative consequences and has been described as a complex "cost-benefit analysis" (Phillips, Walton, & Jhou, 2007). This analysis is based on comparing the positive aspects of the benefits, mainly the reward magnitude (Depue & Collins, 1999) and the aversive aspects of the costs, for example, time spent to achieve the reward or the risk of not achieving it at all (Chong et al., 2015; Hauber & Sommer, 2009). Phillips et al. (2007) suggested a model in which both aspects (costs and benefits) can be described as a hyperbolic function in which a specific threshold has to be reached, so that the behavior to reach the goal is initiated. This threshold is not a fixed point, it varies between situations (e.g., based on the availability of alternatives) and individuals (Walton, Kennerley, Bannerman, Phillips, & Rushworth, 2006; Zald & Treadway, 2017). On a neurophysiological level, dopamine (DA) has been ascribed a central role in this cost-benefit analysis. DA is the predominant catecholamine neurotransmitter inside the brain (Baik, 2013), and the central reward pathway of the brain is the mesocorticolimbic dopamine system (MCLDA). Its widespread neural connections range from the ventral tegmental area and the ventral striatum to regions of the prefrontal cortex (Brooks & Berns, 2013) as well as the anterior cingulate (Hickey, Chelazzi & Theeuwes, 2010). DA binds to a wide range of different receptor types (D1 to D5). Activation of D1 and D5 receptors leads to an excitatory neural reaction and activation of D2, D3 and D4 receptors leads to an inhibitory neural reaction (Serra et al., 1990). Furthermore, the location of the DA receptor (pre-/postsynaptic) alters the effect of its activation (Missale, Nash, Robinson, Jaber, & Caron, 1998; Serra et al., 1990). DA is activated via motivational aspects of approach and avoidance situations (Berridge & Kringelbach, 2008; Salamone, Correa, Mingote, Weber, & Farrar, 2006). According to Depue & Collins (1999), DA promotes goal-directed behaviour and initiation of motor activity, increasing the preference of behavioral options with the highest possible benefit (Nicola, Hopf, & Hjelmstad, 2004; Treadway & Zald, 2011; Walton et al., 2006). According to Phillips et al. (2007), the DA level within the mesolimbic brain structures should directly affect the individual cost-benefit analysis. This assumption is supported by studies in animals (Salamone, Correa, Yang, Rotolo, & Presby, 2018). Pharmacological reduction of DA levels in rodents reduces the willingness to choose behavioral options with high costs and high rewards (Salamone et al., 2016; Yohn et al., 2015), while increasing DA levels has opposite effects (Salamone et al., 2016; Sommer et al., 2014). Moreover, rodents with impaired DA functioning show deficits in their goal-directed behavior (Cannon & Palmiter, 2003; Zhou & Palmiter, 1995).

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In humans, DA activity can be modulated using systemic administration of dopaminergic agents like the selective DA D2 receptor antagonist sulpiride. D2 receptors can be found widespread in various structures of the brain such as the prefrontal, cingulate, temporal, and enthorinal cortex as well as the amygdala and the hippocampus, but highest concentrations of D2 receptors can be found in mesolimbic brain structures, such as the striatum and the nucleus accumbens (NAcc; Missale et al., 1998; Beaulieu, Gainetdinov, & Sibley 2011). Therefore, sulpiride is thought to mainly affect functions of the MCLDA, which is in line with studies investigating sulpiride's clinical effects in the treatment of various mental disorders, for example, depression (Serra et al., 1990; Kuroki, Meltzer, & Ichikawa, 1999), chronic fatigue syndrome (Pardini et al., 2011), or schizophrenia (Miyamoto, Duncan, Marx, & Lieberman, 2005; Lai, Chang, Kao Yang, Lin, & Lin, 2012). However, the intake of sulpiride can have complex effects, which are thought to partly depend on the location of the D2 receptors (pre-/postsynaptic) it primarily blocks (Ford, 2014): low doses of sulpiride are believed to mainly block presynaptic D2/D3 autoreceptors (Kuroki et al., 1999; Mereu, Casu, & Gessa, 1983), resulting in increased DA release and DA synthesis in some parts of the brain (Tagliamonte et al., 1975; Rankin et al., 2009), which might explain its antidepressant effects (Serra et al., 1990; Kuroki et al., 1999). On the other hand, high doses of sulpiride are believed to mainly block postsynaptic D2 receptors thereby lowering DA release and signaling in the brain (Eisenegger et al., 2014; Boschen, Andreatini, & da Cunha, 2015). High doses are therefore used as an antipsychotic drug in patients with schizophrenia (Miyamoto et al., 2005; Lai et al., 2012). Both effects are not completely separable and may occur both in different time frames depending on the precise dose of sulpiride (Mueller, Makeig, Stemmler, Hennig, & Wacker, 2011).

Furthermore, the effects of sulpiride have repeatedly been shown to vary considerably between individuals depending on traits thought to be partly based on individual differences in DA. For example, extraversion is thought to be related to differences in reward processing (Smillie, 2013) and approach motivation in general (Elliot & Thrash, 2002) based on individual differences in DA functioning (Depue & Collins, 1999; Wacker & Smillie, 2015). And indeed, several studies observed that extraversion and related traits completely reversed the effects of sulpiride on various behavioral and neurophysiological measures (Chavanon, Wacker & Stemmler, 2013; Mueller et al., 2014; Wacker, Mueller, Pizzagalli, Hennig, & Stemmler, 2013; Wacker, 2018). For example, sulpiride reduced performance of relatively extraverted and increased performance of relatively introverted participants on a working memory task (Chavanon, Wacker, Leue, & Stemmler, 2007) and a virtual ball-catching task (Mueller et al., 2014). This pattern has been explained by an inverted-U function linking DA activity to behavior with medium DA activity resulting in optimal performance and both extraversion and sulpiride having an impact on DA levels (Chavanon et al., 2013).

Therefore, traits related to DA functioning should always be considered when examining the effects of sulpiride. Studies investigating sulpiride's direct effect on reward processing in humans using behavioral measures are sparse, often focusing on effects of higher dosages of sulpiride (>400 mg). While, for example, Kahnt, Weber, Haker, Robbins, & Tobler (2015) failed to find behavioral changes after the intake of 400 mg amisulpiride within an outcome prediction task, Diederen et al. (2017) found that participants' ability to predict future rewards was reduced after intake of 600 mg sulpiride. Ojala et al. (2018) reported that the intake of 400 mg of sulpiride reduced healthy participants overweighting of low probabilities within a decision-making task, resulting in less risky choices. Weber et al. (2016) found that 400 mg of amisulpiride reduced participants' motivation to choose immediate rewards in a delay-discounting task. Direct evidence for dosage-dependent effects of sulpiride comes from a study conducted by Eisenegger et al (2014). They found that 800 mg sulpiride did not disrupt reward learning within a reinforcement learning task, but reduced number of correct choices of healthy participants only for possible gains not for losses. This effect was directly associated with the serum sulpiride level measured via blood samples, indicating greater impairments are associated with higher serum sulpiride levels. Overall, literature examining sulpiride's main effects on reward processing and approach motivation hints at inhibiting/disrupting effects of higher dosages of sulpiride. However, most studies had small sample sizes, used different tasks, and focused on different aspects of reward processing, reducing generalizability of results and leaving us with a somewhat unsatisfying and incomplete understanding of sulpiride's effects on reward motivation in human. Effects of lower dosage sulpiride on reward processing in humans remain even more unclear.

The sparse literature on sulpiride's effect on reward motivation makes the choice of an appropriate task especially important. One task that has been successfully employed to examine individual differences in reward/approach motivation is the Effort Expenditure for Rewards Task (EEfRT, Treadway, Buckholtz, Schwartzman, Lambert, & Zald, 2009), which is based on a concurrent choice paradigm developed by Salamone, Cousins, & Bucher (1994) to explore effort-based decision-making in rodents. The original EEfRT measures individual differences in human reward processing by having participants decide between high-cost/high-reward (hard task) and low-cost/low-reward (easy task) behavioral options. The tendency to choose the hard task rather than the easy task has been shown to be associated with high levels of approach motivation, as measured,for example, via personality questionnaires (Geaney, Treadway, & Smillie, 2015). According to Smillie (2008), trait behavioral activation system (BAS) sensitivity and extraversion should be predominantly related to reward sensitivity, while trait behavioral inhibition system (BIS) sensitivity and neuroticism should be predominantly related to punishment sensitivity. The EEfRT introduces a reward context, and one would, thus, expect relatively specific associations between behavior in the task and extraversion/trait BAS sensitivity (and their low pole, which is associated with anhedonia; Rizvi, Pizzagalli, Sproule & Kennedy, 2016; Mueller, Panitz, Pizzagalli, Hermann & Wacker, 2015). The mere absence of a reward should have a much smaller impact compared to tasks that introduce a strong punishment (e.g., deduction of money). Healthy participants' preference for the hard task has further been shown to correlate with lower scores on negative affect, depressive symptoms, and anhedonia (Treadway et al., 2009). Recently, we were able to demonstrate that left frontal anodal transcranial direct current stimulation over the dorsolateral prefrontal cortex increased participants' willingness to choose the hard task depending on reward attributes (Ohmann, Kuper & Wacker, 2018), which is in line with models associating left frontal brain activity with approach motivation (Harmon-Jones & Gable, 2017; Rutherford and Lindell, 2011). Wardle, Treadway, Mayo, Zald, & de Wit (2011) were the first to show that the EEfRT is also sensitive to pharmacological manipulation of DA, as d-amphetamine increased participants' overall effort allocation. Further evidence comes from patients suffering from impaired approach motivation: patients with

schizophrenia (Fervaha, Foussias, Agid, & Remington, 2013; Barch, Treadway, & Schoen, 2014; McCarthy, Treadway, Bennett, & Blanchard, 2016), first-episode psychosis (Chang et al., 2019), and depression (Treadway, Bossaller, Shelton, & Zald, 2012; Yang et al., 2014) were less willing to choose the hard task as compared to healthy controls, indicating patients' impaired approach motivation. Furthermore, the number of hard task choices was found to be negatively correlated with the severity of anhedonic symptoms in patients with schizophrenia (e.g., Barch et al., 2014) as well as in patients with depression (e.g., Yang et al., 2014). Anhedonia is closely linked to dysregulated DA functioning within the MCLDA (Pizzagalli et al., 2009; Heshmati & Russo, 2015), which is thought to play a central role in participants' effort allocation. Supporting this notion, Huang et al. (2016) found that the number of hard task choices was directly linked to the activity of the NAcc, which is a key structure of the MCLDA, in both patients with schizophrenia and healthy participants.

Taken together, the EEfRT is a well-established indicator of individual differences in approach motivation thought to be based in individual differences in MCLDA functioning. Thus, manipulating the activity of the MCLDA (e.g., via administration of sulpiride) should influence participants' performance in the EEfRT.

Hypotheses

The main hypotheses and analyses were preregistered at the Open Science Framework on August 9, 2017 after the collection of 70 datasets and before accessing any of the data included in the current analyses (https://osf.io/e5fn9).

Substance group and extraversion

First, we expected a main effect of substance group (sulpiride 200 mg vs. placebo) on approach motivation, which is assessed in terms of individual's willingness to allocate more effort in return for greater rewards within the EEfRT. Second, conceptually replicating prior work on extraversion and DA using pharmacological manipulations of DA, we expected an interaction of extraversion and substance group in the prediction of approach motivation. Previous research has shown that the individual level of trait extraversion is linked to the neuronal and behavioral effects of sulpiride (e.g., Chavanon et al., 2013; Mueller et al., 2014; Wacker et al., 2013; Wacker, 2018), with opposite effects in individuals high versus low in extraversion, possibly due to an inverted-U function linking DA functioning and behavior and certain neural measures. Expecting to observe similar effects using the EEfRT as dependent variable, we predicted that extraversion should increase effort expenditure for individuals low in extraversion and reduce effort allocation in individuals high in extraversion within the sulpiride group as compared to the placebo group.

EEfRT – task validity

For our modified version of the original EEfRT (Treadway et al., 2009; see 2.5 for details on all modifications), we expected effects comparable to the original. We expected the reward attributes (reward magnitude and probability of reward attainment) to be positive predictors of the average number of clicks, whereas we expected trial number (e.g., an indicator of fatigue) to be a negative predictor of the average number of clicks within our modified version of the EEfRT. We only tested right-handed participants, who typically show worse motoric performance with their left hand on finger tapping tests (Hervé, Mazoyer, Crivello, Perchey, & Tzourio-Mazoyer, 2005). Therefore, we expected the factor hand to be a significant predictor of the average number of clicks, as participants should make fewer clicks with their left hand due to the increased effort requirements. As our modifications might have increased the influence of motoric abilities and this is the first study to use these modifications, we ran a pre-analysis to see whether higher motoric abilities are associated with greater average number of clicks throughout the actual task and should therefore be statistically controlled for in the analyses.

Secondary analysis

To further validate our modified EEfRT, we analyzed the correlations between extraversion, BIS/BAS, and effort allocation in the task. Previous research has shown positive correlations between BAS and task performance on the original EEfRT in trials with low probability of reward attainment (Geaney et al., 2015), which we also expected for our modified version. To probe the specificity of these effects, we exploratorily correlated effort expenditure with other personality variables. Finally, we checked for the effect of previous trial feedback based on research by Anand, Oehlberg, Treadway, & Nusslock (2016), who found that feedback of a previous task impacted participants' performance in the following EEfRT task. Comparable to Anand et al. (2016), we expected negative feedback within the previous trial (no money won) to reduce participants' average number of clicks as compared to positive feedback (money won). Additionally, we checked for possible moderating effects of substance group and extraversion on feedback in an exploratory fashion. As previous trial feedback is not present in the first trial of each block, these two trials were excluded from these analyses.

1. Methods

1.1 Participants

We recruited right-handed, physically and psychologically healthy male participants aged 18–35 years using online notice boards, advertising via blackboard postings, flyers, and recruiting booths at local universities (University of Hamburg, Germany; Helmut-Schmidt University, Germany; Hochschule für Angewandte Wissenschaften Hamburg, Germany). Out of 210 recruited participants, 7 had to be excluded for different reasons (4 showed uncompliant behavior, e.g., not following instructions; 2 were unable to swallow the capsule; 1 dataset was lost due to technical failure). Thus, the final sample consisted of 203 participants (age: $M = 25.10$; $SD = 3.94$), 102 participants within the sulpiride group and 101 participants within the placebo group. As can be seen in Table 1, participants of the two substance groups did not differ in any of the main demographic variables assessed before the testing session (age, BMI, fluid and crystallized IQ, BIS/BAS; extraversion). The significant difference in motoric trials assessed while participants were under the influence of placebo/sulpiride is discussed in Section 1.5.

A sensitivity power analysis was carried out to determine our statistical power to detect differences in correlations between extraversion and effort expenditure in the two substance groups. Our statistical power was 80% for the detection of Fisher's z-transformed correlation differences of .40 at $\alpha = .05$. This corresponds, for instance, to a correlation of $r = .20$ in the placebo, and $r = -.20$ in the sulpiride group. Participants received monetary compensation (10€ per hour) and were told that they could gain

Table 1. Simple *t*-test comparisons of main demographics and covariates for both substance groups

	Sulpiride condition		Placebo condition			
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Age	25.32	3.91	24.79	3.99	0.95	0.342
BMI	24.13	2.86	23.93	2.89	0.49	0.624
Fluid IQ	116.56	13.41	113.48	15.69	1.51	0.134
Crystallized IQ	101.29	12.36	101.77	13.55	−0.26	0.793
BIS	17.44	3.35	16.80	3.04	1.42	0.156
BAS	39.82	4.02	39.67	3.81	0.27	0.785
Extraversion	162.28	18.25	161.56	16.89	0.29	0.771
MaxMot-L	118.85	18.39	119.24	21.13	−0.14	0.890
MaxMot-R	131.18	19.15	137.01	19.69	−2.14	**0.034**

BMI = body mass index; fluid IQ = intelligence quotient of fluid intelligence; crystallized IQ = intelligence quotient of crystallized intelligence; BIS = behavioral inhibition system; BAS = behavioral activation system; MaxMot-L= maximum number of clicks within motoric trials exhibited with the left hand; MaxMot-R = maximum number of clicks within motoric trials exhibited with the right hand. Significant effects in bold.

additional money based on their collected rewards from two computer tasks. At the end of the study, we revealed to all participants that the additional money was fixed at 10€ (which was generally higher than the rewards collected while playing) to ensure equity. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The study has been approved by the Human Research Ethics Committee of the DGPs (Deutsche Gesellschaft für Psychologie).

We applied strict exclusion criteria to ensure maximum safety for all participants. Exclusion criteria comprised the intake of any kind of prescribed medication over the last 3 months, the consumption of illegal drugs over the last 3 months, the consumption of more than 10 cigarettes per week, high blood pressure (above 140/90) and/or an irregular heartbeat as tested on site using an automatic blood pressure monitor, lifetime medical conditions (in particular epilepsy, endocrinopathies, hypertension, coronary heart disease, bleeding or disease of the bowel, disease of the liver or kidneys), the presence of any mental disorders as diagnosed via DSM-V criteria over the last 3 months (in particular affective, somatoform, psychotic, anxiety, eating, and adaptive disorders, as well as mental disorders triggered by drug abuse) using a standardize clinical interview (Mini-DIPS, Margraf, 1994), and any known allergic reactions to sulpiride or other psychoactive substances.

1.2 Manipulation

In a randomized, double-blinded between-subjects design, participants either received a capsule with 200 mg of the DA D2 receptor antagonist sulpiride (e.g., the same dose used by Wacker et al., 2013; Wacker, Chavanon, Stemmler, 2006) or a non-distinguishable placebo. Sulpiride is a substituted benzamide, which is generally well tolerated (Ruther et al., 1999). We decided to use a rather low dosage of 200 mg of sulpiride, because in lower doses sulpiride is believed to have a high affinity to presynaptic autoreceptors and therefore presumably elevates DA levels (Tagliamonte et al., 1975; Rankin et al., 2009) resulting in a mild stimulant effect. This stimulant effect is for example used in the treatment of depression (Serra et al., 1990; Kuroki et al., 1999). This contrasts with higher dosages of sulpiride (>400 mg), which are believed to additionally affect postsynaptic autoreceptors and therefore reducing DA levels, resulting in an overall inhibiting effect (Eisenegger et al., 2014; Boschen et al., 2015) used as an antipsychotic drug in patients with schizophrenia (Miyamoto et al., 2005; Lai et al., 2012). Sulpiride is slowly absorbed from the gastrointestinal tract, with peak serum levels occurring 1 to 6 h after oral ingestion; the average elimination half-life is in the range of 3 to 10 h (Mauri, Bravin, Bitetto, Rudelli, & Invernizzi, 1996).

1.3 Randomization

Participants were tested in groups of four (or three, in case one scheduled participant did not appear). Substance condition was assigned with a restricted randomization in order to ensure (1) equal numbers of participants for both conditions and (2) balanced conditions within each group session. For each group testing of four participants, two participants were randomly assigned to the placebo and two to the sulpiride condition based on their assigned identification number. For groups with three participants, the condition originally assigned to the fourth participant's identification number was dropped.

1.4 Procedure

Potential participants took part in a 5-min screening interview (per telephone or in person) which served as a first screening instrument for in- and exclusion criteria. Individuals who appeared eligible for participation were invited into our lab twice (presession and main experimental session).

In the presession, participants received detailed information about sulpiride and the double-blind experimental procedure and gave their informed consent. They were further informed that they were required to refrain from eating and consuming caffeine and nicotine starting 11.5 h (from 22:00 on the day before the test session) before their schedule session. Afterward, the in- and exclusion criteria were checked thoroughly. If all in- and exclusion criteria were met, participants filled out a series of questionnaires, including demographic information, the German BIS/BAS (Strobel, Beauducel, Debener, & Brocke, 2001), and the German NEO-PI-3 (unpublished translation from the NEO-PI-3; Costa

& McCrae, 2010) to assess participants' personality and made an appointment for the main experimental session.

Three or four participants took part in the main experimental session, which started at 9:30. The experimenters inquired whether the participants had indeed refrained from eating and consuming caffeine/nicotine as required and whether they were in good physical condition. Participants then had a standardized, light breakfast and took the assigned capsule. On average, participants started at 9:54 AM ($SD = 6$ min) by completing six computer-based subtests of the Intelligence Structure Battery (INSBAT, Arendasy et al., 2012) to access participants' fluid and crystallized intelligence. Afterward, participants completed a series of tasks, which are not relevant to the current research question (for further information, see https://osf.io/phr4g). Participants completed the modified EEfRT (see Section 1.5) at 12:55 PM ($SD = 17$ min). After two further tasks, data from which will be reported elsewhere (e.g., Käckenmester, Bott, Wacker, 2019), participants completed a short questionnaire about the surrounding conditions of the lab during the main session, their subjective perceptions of the effects of the sulpiride/placebo intake, and their presumptions concerning the purpose of the study. Finally, participants received written information about the study and their experimental condition (sulpiride or placebo) along with instructions on how to act in case they noticed any side effects, including contact information for emergencies (only sulpiride condition), and were reimbursed for their participation.

1.5 Effort-expenditure for reward task

We used a modified and translated (German) version of the EEfRT (Treadway et al., 2009), which was programmed using Presentation software 17.1 (Neurobehavioral Systems Inc, San Francisco). The original EEfRT intends to measure participants' approach motivation by testing their willingness to exert effort to gain possible monetary rewards. Participants choose between an easy, low-reward task and a hard, high-reward task in every trial. The easy task requires participants to press the space button 30 times in 7 s with their index finger. The hard task requires participants to press the space button 100 times in 21 s with their pinkie finger. The reward for the easy task is fixed to 1€, while the reward for the hard task is variable (ranging between 1.21€ and 4.30€). Furthermore, before the start of each trial, participants are informed about the probability of attaining the reward after successfully completing the trial. The probability is equal for both the easy and the hard task within each trial. In a previous study (Ohmann et al., 2018), we found that using the original EEfRT also comes with a major downside: at least some participants understand that choosing the hard task is often lowering the possible overall monetary gain as the hard task takes almost three times as long as the easy task. Hence, at least some participants' choices are partly based on a strategic decision and less on approach motivation per se. To overcome this downside, we modified the original EEfRT. First, we fixed the number of trials (2 blocks × 15 trials = 30 trials) and the duration of each trial (= 20 s). Participants use their right hand for one block and their left hand for the other block, and the order of both blocks is randomized. Second, we changed the original choice paradigm. Participants no longer choose between an easy and a hard task. As in the original task, the value of each reward varies, and participants are informed about this at the start of each trial. But instead of presenting specific reward amounts, participants are now presented with a reward amount per click (1/2/3/4/5 cents per click). Thus, participants are able to increase the total possible monetary gain in each trial with each click. In accordance with the original task design, the probability of reward attainment also varied [either 12% (low), 50% (middle), or 88% (high)], which is presented at the start of each trial alongside the reward value per click. Participants were instructed to win as much virtual money as possible throughout the task; however, they were free to choose the amount of effort they exerted in each trial. Critically, the only way to increase the possible monetary gain is to increase the number of clicks in each trial. The task itself is designed close to the original EEfRT but comes with some modifications to prevent the use of strategies (see Figure 1): while pressing the spacebar, a visually presented red bar gradually grows. We implemented a scale (€), so that the participants can always see how much their button presses increase their possible monetary gain. Furthermore, we decided to present the information on the reward amount per click and the probability of attaining the total reward amount in the specific trial throughout the whole trial alongside a countdown (20 s) to increase participants' awareness of these parameters. After each trial, participants are informed about the amount of money they won during the trial. The order of trials, as well as the probability of reward attainment and the reward magnitudes per click are not randomized between participants, but preassigned for each trial. This is done to rule out random feedback differences between participants. Because it is likely that participants with greater motoric ability exert more clicks throughout the task, which does not reflect their actual approach motivation, we included 10 motoric trials (5 at the start of each block, using either the left or the right hand according to the randomized block order) to test participants' motoric abilities. Within these motoric trials, participants were instructed to press the spacebar as often as possible within 20 s. Critically, participants were not able to gain any rewards in these trials, and visual feedback was reduced to a countdown and a display of the number of clicks they exerted. Participants' individual motoric abilities were included in our statistical models. Although the inclusion of this factor was not preregistered, we decided to do so, because our preliminary analyses (see Section 2.1) revealed a large impact of participants' individual motoric abilities on the number of clicks they exerted and participants of both substance groups also differed in their motoric abilities as measured via the motoric trials, as participants within the sulpiride condition did show lower motoric abilities (see Table 1). Therefore, not including this factor could have distorted the results.

1.6 Data analysis

Aggregated data were further analyzed using the SPSS 22.0 software (Chicago, IL, USA). Effects on the number of clicks while playing the modified EEfRT were analyzed using Generalized Estimating Equations (GEEs). GEEs are marginal models that allow for robust parameter estimation despite correlated residuals, for example, due to the clustering of trials within participants (Liang, Beaty, & Cohen, 1986; Zeger & Liang, 1986). The models were fit using an exchangeable working correlation matrix. Crucially, they are consistent even when the correlation matrix for the residuals is specified incorrectly. All GEE models included the factors block, trial number, hand, probability (categorical), reward magnitude, the interaction of probability × reward magnitude (sometimes referred to as "expected value"), and participants' individual motoric abilities. Separate models were computed to test basic predictors of "number of clicks", the effects of substance group (sulpiride/placebo) on "number of clicks", as well as

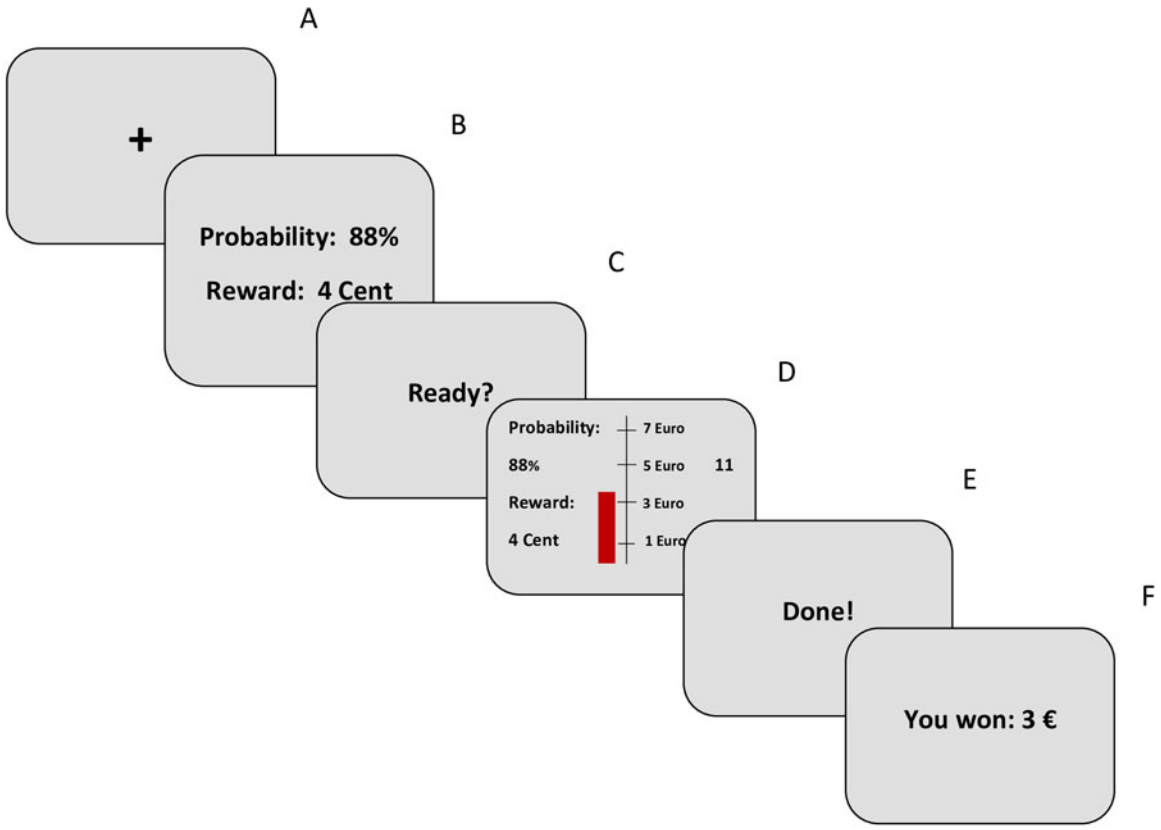

Figure 1. Schematic illustration of one trial of the modified EEfRT. A fixation cross (1s, A) is followed by a screen showing probability of reward attainment and reward magnitude per click for 3s (B). Then, after a ready – screen (1s, C), the main screen for the trial showing a red bar that grows with each click is presented alongside a scale, indicating the current monetary gain and a countdown (20s, D). Finally, task completion is signaled (1,5s, E) and a feedback screen shows the amount of money won (2s, F).

interactions between substance group and reward attributes (reward magnitude and probability of reward attainment). Pearson's correlations were computed between trait variables (BAS/extraversion/etc.) and mean number of clicks within the modified EEfRT adjusted for individual motoric abilities separately for each probability of reward attainment (low/medium/high).

As mentioned above, the main hypotheses and analyses were preregistered at the Open Science Framework on August 9, 2017 after the collection of 70 datasets and before accessing any of the data included in the current analyses (https://osf.io/e5fn9). The results of the other tasks addressed in the preregistration were part of the larger project investigating the effects of DA on behavioral measures and will be reported elsewhere.

2. Results

2.1 Preliminary analysis – influence of motoric abilities

We ran a pre-analysis to probe whether higher motoric ability is associated with greater average number of clicks throughout the actual task. Therefore, we correlated the data of participants' motoric trials, both maximum number of clicks (left hand = MaxMot-L; right hand = MaxMot-R) and average number of clicks (left hand = AvMot-L; right hand = AvMot-R) with the average number of clicks within the actual task. Participants on average exerted a maximum of 134.08 ($SD = 19.59$) clicks within motoric trials with their right hand and a maximum of 119.04 ($SD = 19.75$) clicks on motoric trials with their left hand, and the difference between both hands was significant ($t(202) = 11.41$, $p < .001$). MaxMot-L showed significant positive correlations with the average number of clicks within trials exerted with the left hand ($r = .585$, $p < .001$) as well as within trials exerted with the right hand ($r = .580$, $p < .001$). MaxMot-R also showed significant positive correlations with the average number of clicks within trials with the left hand ($r = .477$, $p < .001$) as well as with trials with the right hand ($r = .648$, $p < .001$). The pattern for the average number of clicks within motoric trials was highly comparable and including the average number of clicks within motoric trials in the main analyses instead did not change the results in a significant way.

2.2 Preliminary analysis – reliability of the EEfRT

We calculated the reliability of the mean number of clicks. Therefore, the mean number of clicks of each participant was residualized on his motoric abilities. Reliability estimates were obtained by correlating the adjusted number of clicks of both hands (out of two blocks, one was conducted with the right hand and one with the left hand) and applying a Spearman's brown correction to the resulting estimate. The overall mean number of clicks showed a high correlation between both hands (Rel = .78). When separately analyzing the data for each probability and reward amount per click, correlations ranged between Rel = .67 and Rel = .87. The overall high correlations indicate a robust reliability of the modified EEfRT.

2.3 Validity of the modified EEfRT

Participants on average exerted 121.00 clicks per trial ($SD = 16.70$; range = 76.43–172.37). We conducted a series of GEE models to

Table 2. GEE models for basic predictors of average number of clicks (EEfRT)

Effect	β	*se*	χ^2	*p*
Model 1				
Reward magnitude	5.11	0.40	160.13	**<.001**
Probability 50%[a]	17.10	1.69	102.26	**<.001**
Probability 88%[a]	25.36	1.86	185.97	**<.001**
Probability 50%[a] × Reward magnitude	0.37	0.36	1.07	.302
Probability 88%[a] × Reward magnitude	−1.04	0.35	8.58	**.003**
Trial	−0.26	0.04	45.73	**<.001**
Hand	11.99	0.85	199.49	**<.001**
Block	−1.52	0.85	3.22	.073
MaxMot-L	0.43	0.15	8.12	**.004**
MaxMot-R	0.22	0.11	4.19	**.041**
Model 2				
MaxMot-L × Hand	−0.16	0.08	3.52	.061
MaxMot-R × Hand	0.18	0.06	8.35	**.004**
Model 3				
MaxMot-L × Reward	−0.01	0.02	2.38	.683
MaxMot-R × Reward	0.03	0.02	0.17	.123
Model 4				
MaxMot-L × Probability 50%[a]	−0.01	0.06	0.05	.817
MaxMot-L × Probability 88%[a]	−0.06	0.07	0.75	.386
MaxMot-R × Probability 50%[a]	0.07	0.08	0.84	.359
MaxMot-R × Probability 88%[a]	0.09	0.08	1.26	.262

Note. All models included probability (categorical), reward magnitude, trial number, block, hand as within-subjects variables, and MaxMot-L and MaxMot-R as between subject variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in bold.
[a]Reference category: 12% probability.

test the validity of the modified EEfRT (see Table 2, GEE model 1–4). GEE model 1 examined main effects of task-dependent variables (reward magnitude, probability of reward attainment, and trial number) as well as four variables unique to our study (block, hand, MaxMot-L, and MaxMot-R) on the average number of clicks. In line with previous studies, significant positive main effects were found for probability (see Figure 2) and reward magnitude (see Figure 3), and a significant negative main effect was found for trial number, indicating that all three factors were predictors of average number of clicks (all *p*s < .001). The factor block did not reach significance ($\beta = -1.52$, $\chi^2(1) = 3.22$, $p = .073$), indicating that there were no appreciable differences in average number of clicks between both blocks. In accordance with our previous work with the original EEfRT, the factor hand reached significance ($\beta = 11.99$, $\chi^2(1) = 0.90$, $p < .001$), indicating that participants clicked the button more often with their right hand.

MaxMot-L and MaxMot-R both reached significance, indicating that participants with greater motoric ability as measured within the motoric trials also exerted more clicks within the modified EEfRT, which is in line with the pre-analysis we conducted showing significant positive correlations (see Section 2.1). Model 2 revealed a significant interaction of hand used within the task and MaxMot-R ($\beta = 0.18$, $\chi^2(1) = 8.35$, $p = .004$), whereas the analogous interaction failed to reach significance for MaxMot-L ($\beta = -0.16$, $\chi^2(1) = 3.52$, $p = .061$). As both models indicate motoric abilities to influence task performance (supporting our preliminary analysis, see Section 2.1), we decided to include both factors as well as their interactions with the hand used within the task in all following models. Two additional GEE models (see Table 2, model 3–4) tested possible interactions of participants' motoric ability and reward attributes. None of these interactions reached significance, indicating that participants' motoric abilities did not affect task performance depending on reward attributes.

2.4 Effects of sulpiride and extraversion

Overall, three GEE models were computed to test the effects of sulpiride on the average number of clicks within the modified EEfRT (see Table 3, GEE model 5–7). In model 5, we tested the main effect of substance group on the average number of clicks, which reached significance ($\beta = -4.16$, $\chi^2(1) = 7.26$, $p = .007$), indicating that participants showed a reduced average number of clicks under sulpiride. In model 6 and 7, we analyzed the interaction of substance group with reward magnitude and probability and found that the effect of sulpiride on average number of clicks was not moderated by either of the two factors (see Figure 2 and 3). Three further GEE models (see Table 3, GEE model 8–10) tested the effect of trait extraversion on average number of clicks within the modified EEfRT. Model 8 revealed a main effect of extraversion ($\beta = 1.71$, $\chi^2(1) = 4.52$, $p = .034$), indicating that participants with higher trait

Table 3. GEE models of substance group and extraversion effects on average number of clicks (EEfRT)

Effect	β	*se*	χ^2	*p*
Model 5				
Substance	−4.16	1.54	7.26	**.007**
Model 6				
Substance	−5.12	2.49	4.21	**.040**
Substance × Reward Magnitude	0.32	5.67	0.32	.573
Model 7				
Substance	−6.76	2.69	6.34	**.012**
Substance × Probability 50%[a]	3.69	2.33	2.51	.113
Substance × Probability 88%[a]	4.12	2.63	2.46	.117
Model 8				
Extraversion	1.71	0.80	4.52	**.034**
Model 9				
Extraversion	1.10	1.14	0.94	.333
Extraversion × Reward Magnitude	0.20	0.28	0.53	.468
Model 10				
Extraversion	3.82	1.53	6.22	**.013**
Extraversion × Probability 50%[a]	−3.21	1.45	4.20	**.027**
Extraversion × Probability 88%[a]	−3.13	1.53	4.90	**.041**
Model 11				
Substance	−4.27	1.52	7.92	**.005**
Extraversion	1.33	1.16	1.32	.252
Substance × Extraversion	0.83	1.54	0.29	.593
Model 12				
Substance	−20.28	14.89	1.86	.173
Substance × MaxMot-L	0.26	0.18	2.12	.145
Substance × MaxMot-R	−0.11	0.15	0.55	.457

Note. All models included probability (categorical), reward magnitude, trial number, block, hand as within-subjects variables, and MaxMot-L and MaxMot-R as between subject variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in bold.
[a]Reference category: 12% probability.

extraversion exerted a higher average number of clicks. While model 9 revealed no significant interaction of extraversion and reward magnitude, model 10 revealed a significant interaction of extraversion and probability. Comparing low versus high probability ($\beta = -3.13, \chi^2(1) =, p = .027$) as well as comparing low and medium probability trials ($\beta = -3.21, \chi^2(1) =, p = .041$) revealed significant interactions with extraversion, due to participants with higher extraversion being less affected by the probability of reward attainment than participants with lower extraversion (see Figure 4). In GEE model 11, we tested for a possible interaction of substance group and trait extraversion, which was not significant. GEE model 12 was computed to test for a possible interaction of substance group and participants' motoric abilities, which was also not significant, indicating that sulpiride did not alter the association between average number of clicks within the modified EEfRT and motoric abilities.

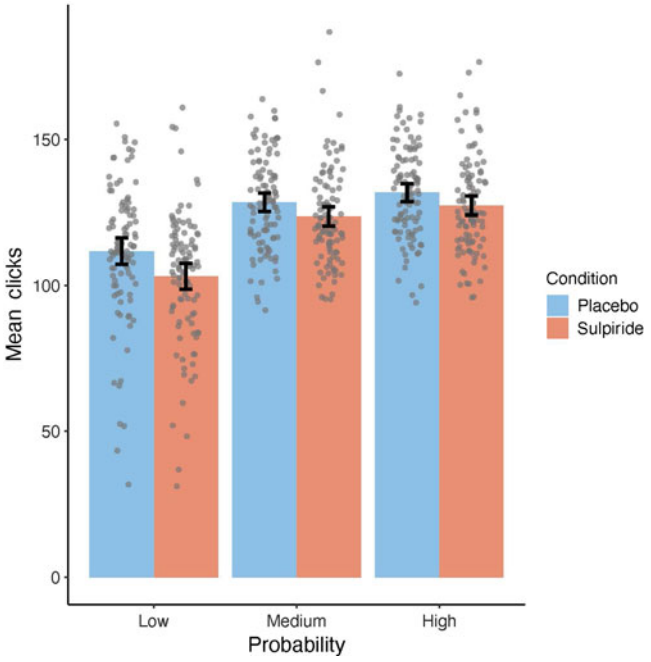

Figure 2. Mean number of clicks adjusted for participants' motoric abilities, comparing trials with low probability of reward attainment (left), medium probability of reward attainment (middle), and high probability of reward attainment (right) as compared between both substance groups (sulpiride groups is shown in red and placebo group is shown in blue). Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

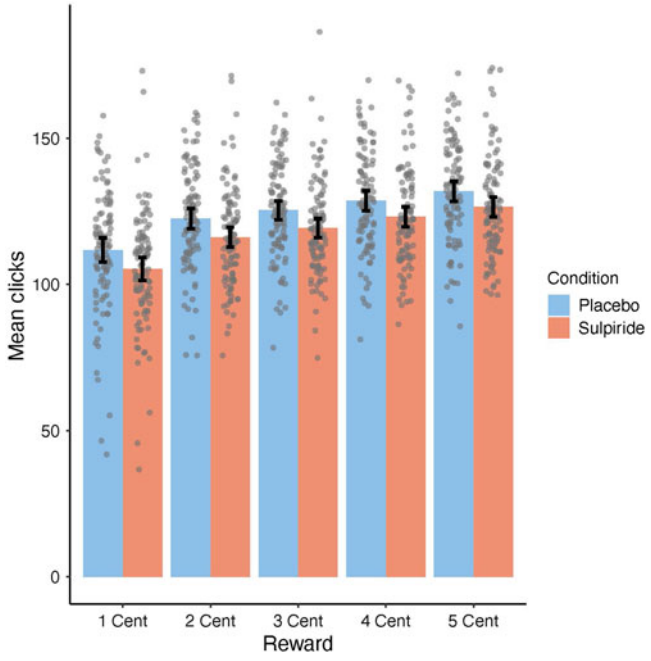

Figure 3. Mean number of clicks adjusted for participants' motoric abilities, comparing trials with different reward magnitude per click, ranging from 1 cent (most left) to 5 cent (most right) as compared between both substance groups (sulpiride groups is shown in red and placebo group is shown in blue). Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

Table 4. Zero-order correlations between EEfRT average number of clicks and trait variables

	Reward probability		
Trait variable	12%	50%	88%
BAS	**0.212****	0.124	0.103
BIS	−0.081	0.081	0.052
Extraversion	**0.193****	0.051	0.054
Openness	**0.159***	0.039	0.024
Conscientiousness	0.113	0.033	0.023
Neuroticism	−0.093	0.072	0.062
Agreeableness	−0.052	0.035	−0.016

Note. EEfRT = Effort Expenditure for Rewards Task; BAS = behavioral activation system; BIS = behavioral inhibition system scale; significant effects in bold. * $p < .05$ ** $p < .01$.

2.5 Secondary analyses

To further validate our modified EEfRT, we correlated the average number of clicks within the task (adjusted for participants' individual motoric abilities, see section 2.1) with the personality traits extraversion and BIS/BAS. Several other personality traits were exploratorily included to test the specificity of the effects (see Table 4). As expected, trait BAS correlated positively with the adjusted number of clicks within trials with low probability of reward attainment mirroring the pattern observed for extraversion. The correlation between extraversion and the adjusted number of clicks did not differ significantly between the substance groups (placebo: $r = .09$, sulpiride: $r = .21$, $Z_{diff} = 0.86$, $p = .391$). These findings were similar for trait BAS (placebo: $r = .09$, sulpiride: $r = .32$, $Z_{diff} = 1.71$, $p = .086$). However, openness also correlated positively with the adjusted number of clicks within trials with low probability of reward attainment. None of the other personality traits correlated significantly.

Additionally, based on Anand et al.'s (2016) findings, who used the original EEfRT, we tested for a possible impact of feedback. But instead of investigating previous task feedback, we tested for the impact of previous trial feedback (money won vs. no money won in the previous trial). We computed three additional GEE models (13–15, see Table 5). GEE model 13 revealed a highly significant impact of previous trial feedback, indicating that negative feedback significantly reduced the average number of clicks within the task as compared to positive feedback. GEE model 14 and 15 were conducted in an exploratory fashion, to check for a possible moderating effect of substance group and extraversion. Both models revealed that the effect of previous trial feedback on the average number of clicks was neither moderated by substance group nor by extraversion.

3. Discussion

In the present study, we aimed to (1) validate our new modified version of the EEfRT (Treadway et al., 2009) as a measure of DA-based approach motivation and (2) conceptually replicate the modulating effect of extraversion on a pharmacological manipulation of DA using the modified EEfRT as a dependent variable more directly tapping into approach motivation than the variables examined in previous studies (e.g., Wacker, 2018; Wacker et al., 2013). We will discuss the implication of the current findings for each of these goals.

Table 5. GEE models of feedback effects on average number of clicks (EEfRT)

Effect	β	*se*	χ^2	*p*
Model 13				
Feedback	2.27	0.35	41.54	**<.001**
Model 14				
Feedback	2.15	0.53	16.25	**<.001**
Substance	−6.97	2.87	5.90	**.015**
Substance × Probability 50%	3.94	2.40	2.69	.101
Substance × Probability 88%	4.17	2.69	2.40	.121
Substance × Feedback	0.24	0.80	0.09	.762
Model 15				
Feedback	2.27	0.35	42.49	**<.001**
Extraversion	3.43	1.59	4.67	**.031**
Extraversion × Probability 50%	−3.14	1.47	4.56	**.033**
Extraversion × Probability 88%	−3.01	1.55	3.79	.051
Extraversion × Feedback	0.57	0.36	2.50	.114

Note. All models included probability (categorical), reward magnitude, trial number, block, hand as within-subjects variables, and MaxMot-L and MaxMot-R as between subject variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in bold.
[a]Reference category: 12% probability.

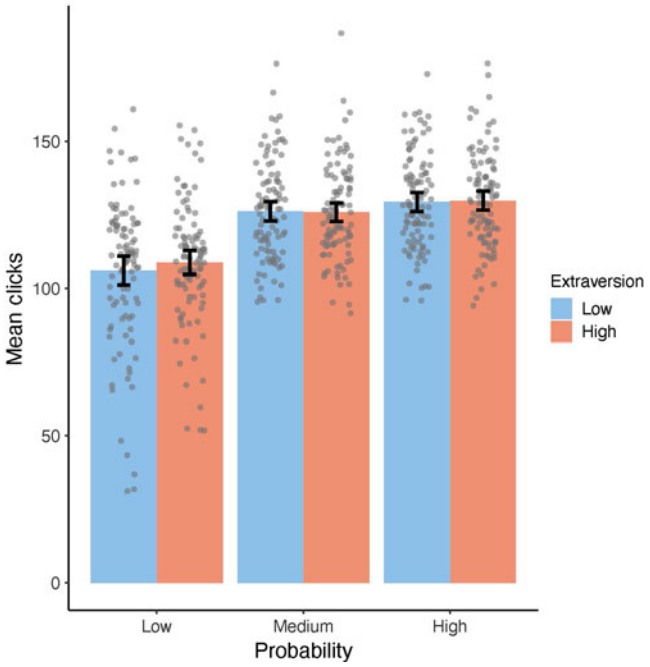

Figure 4. Mean number of clicks adjusted for participants' motoric abilities, comparing trials with low probability of reward attainment (left), medium probability of reward attainment (middle), and high probability of reward attainment (right) as compared between participants with high extraversion (shown in red) and participants with low extraversion (shown in blue). Extraversion categories were obtained by splitting data into two equally sized groups. Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

3.1 Validity of the modified version of the EEfRT

Supporting the validity of our modified task, the pattern of effects of reward, probability, trial, hand, and block on the average number of clicks closely matched the pattern typically observed for the

original EEfRT. Previous studies investigating the psychometric properties of the original EEfRT in a clinical sample (schizophrenic patients) and a healthy control sample found robust reliability, exceeding the reliability of four other effort-based decision-making tasks (Reddy et al., 2015; Horan et al., 2015). Our results indicate that the reliability of the modified EEfRT is also high. Furthermore, we observed positive correlations between extraversion, trait BAS as well as openness and the number of clicks only in trials with low probability of reward attainment. This is in line with studies indicating that especially trials with low probability of reward attainment are associated with different indicators of approach motivation (e.g., Geaney et al., 2015). The fact that some studies failed to find associations between BAS/extraversion and indicators of approach motivation obtained from the original EEfRT could be partly due to confounding strategic choices of participants limiting the validity of the original task (Ohmann et al., 2018). Note, however, that additional data of two smaller studies conducted in our laboratory using the modified EEfRT in different contexts hint at a smaller effect size for this association when combined with the current findings (results will be published elsewhere).

The current observation of a main effect of the DA D2 receptor blocker sulpiride on the average number of clicks after controlling for motor performance provides some support for the validity of the modified EEfRT as a measure of DA-based approach motivation. However, it should be noted that we had predicted an increasing rather than a reducing effect of sulpiride on the average number of clicks based on the assumption that the relatively low dose of 200 mg primarily blocks presynaptic autoreceptors, resulting in a reduction of postsynaptic DA activity (Kuroki et al., 1999; Mereu et al., 1983), thus increasing approach motivation. Studies investigating sulpiride's effects on reward processing and its neurophysiological correlates often use higher dosages of up to 800 mg resulting in predominantly inhibiting effects (Diederen et al., 2017; Ojala et al., 2018; Weber et al., 2016; Eisenegger et al., 2014). However, it might be possible that administering a single dose of sulpiride evokes inhibiting effects even when used in smaller dosages. Furthermore, the effects of sulpiride have been repeatedly observed to depend on complex interactions of various factors, including dosage, time since intake, and incentive context (Chavanon et al., 2013; Mueller et al., 2014). Therefore, the specific setup of our study might have led to the unexpected direction of the observed effect.

A finding that is limiting the validity of the modified EEfRT in the current study is that the effects of sulpiride neither interacted with reward magnitude nor with reward probability, indicating that the inhibiting effect of sulpiride was independent of reward attributes. Previous studies indicated that EEfRT trials with a low probability of reward attainment are most sensitive to pharmacological manipulations of DA (Wardle et al., 2011), manipulation of asymmetric frontal brain activity (Ohmann et al., 2018), trait differences in approach motivation (Geaney et al., 2015), or clinical impairments of approach motivation (e.g., McCarthy et al., 2016; Yang et al., 2014). The current observation that trait BAS and trait extraversion significantly correlated only with the number of clicks within trials with low probability of reward attainment also matches this pattern. One possible explanation for the missing interaction of substance and reward attributes in our study could be a general decrease in effort independent of rewards.

Decision-making tasks like the original EEfRT (Treadway et al., 2009) and comparable tasks differentiate "effort" and "reward" as two (still interdependent) variables that participants can base their decisions on and have shown that increases in DA can lead to effort-specific changes (Le Heron et al., 2018; Filla et al., 2018; Chong et al., 2015) or reward-specific changes (Skvortsova, Degos, Welter, Vidailhet & Pessiglione, 2017) in performance. For example, Le Heron et al. (2018) showed that participants with Parkinson's disease accept tasks that require higher effort more often, but not tasks with higher rewards when being under DA medication as compared to no DA medication. However, acceptance rate was already very high for high reward conditions (as compared to high-effort conditions) even under no medication – hinting at possible ceiling effects. There are at least two reasons to assume that our modified EEfRT measures changes in approach motivation: first, participants choose to invest a varying amount of clicks depending on the reward attributes introduced in each trial (see Figures 2 and 3), a pattern which is highly comparable to the results of the original EEfRT (e.g., Treadway, et al., 2009; Ohmann et al., 2018). Therefore, we assume that number of clicks invested in each trial is an active decision itself, as each click increases the possible monetary gain. Second, we introduced motoric trials without any rewards before each block of the modified EEfRT and used performance in these to control for motor performance/motoric vigor. Effects of reward magnitude and extraversion/trait BAS were found even with this control.

Unexpectedly, participants within the sulpiride group showed worse performance in the motoric trials. Therefore, it is possible that sulpiride reduced participants' motoric performance. Nonetheless, the variance introduced via the (reduced) motoric abilities was at least partly controlled by our including performance in the motoric trials in all GEE models (see Section 2.1).

Taken together, the current pattern of results provides initial support for the validity of the modified version of the EEfRT as a measure of approach motivation and also hints at a possible sensitivity of the task to manipulations of DA. However, the limiting factors (global effect of sulpiride and impact of motoric abilities) call for further improvements of the task design. For example, further motoric trials could be introduced before study manipulations, as these could be used to measure participants "baseline" motoric performance. More research with samples at least as large as in the present study is needed to delineate the effects of both trait BAS/extraversion and manipulations of DA levels on approach motivation as measured by the (modified) EEfRT. Until then, the current observation of a reducing effect of 200 mg sulpiride on the number of rewarded clicks in our modified EEfRT only provides limited support for an influence of DA on performance in the task. Nonetheless, we tentatively recommend use of the modified version of the EEfRT to compensate for the limitations of the original task (Ohmann et al., 2018). Note, however, that these limitations may only apply when overall reward in the original EEfRT is based on the total reward amount obtained across all trials (e.g., Hughes et al., 2015) rather than on the reward obtained in two randomly chosen trials (Treadway et al., 2009). The impact of such seemingly subtle task variations is hardly investigated and may often be underestimated.

3.2 Conceptual replication of a modulating effect of extraversion on a pharmacological manipulation of DA

In contrast to several previous studies using an identical dose of the same pharmacological agent (e.g., Wacker, 2018; Wacker et al., 2013), we did not observe the expected modulating effect of trait extraversion on the effects of sulpiride. This surprising absence of the expected effect despite encouraging support for the validity

of the modified EEfRT and use of a relatively large sample is difficult to interpret. Possibly differences between studies in timing of substance and task administration or incentive context might play a role in this respect (see Section 4.1. Furthermore, we assessed participants' trait extraversion and might have missed out on substance-induced changes in state extraversion. Such changes in state extraversion might have affected participants' performance and should be assessed in future studies. Alternatively, the moderating effects of extraversion may be more pronounced for sulpiride's effects on cognitive control (Wacker, 2018) and working memory (Wacker et al., 2006) than on approach motivation as measured by our modified EEfRT.

Ideally, future studies should either systematically compare various tasks and contexts while controlling for time since administration of various doses of sulpiride or incorporate more direct assessments of sulpiride's effects in the brain (e.g., using positron emission tomography with appropriate tracers) in order to disentangle effects of time/drug metabolism and task/context variability.

3.3 Limitations

Although the present study features a relatively large sample size, controls for a wide range of potential confounding factors, and offers a careful examination of the validity of our modified version of the EEfRT, several limitations should also be mentioned. First, our sample consisted of only male participants aged between 18 and 35 years, most of whom were college students. Therefore, generalizability of our results is necessarily limited. Additionally, we used a between-subject design to counteract possible learning effects between study days. However, a within-subject design could be more sensitive to detect the moderating effect of extraversion. More importantly, small effect sizes seem to be quite common in psychology (Open Science Collaboration, 2015; Gignac & Szodorai, 2016) and we did not find equally strong relationships between BAS/extraversion and behavior in the modified EEfRT in two smaller samples using different contexts (results will be published elsewhere), the present study may still be underpowered and future studies may be well advised to share the load of data collection among several laboratories to achieve sufficient power for more modest effects within a reasonable time frame. Furthermore, although we considered participants' motoric abilities and accounted for this variance by adding motoric trials to the modified EEfRT, the large impact of motoric abilities may still be considered a possible downside of this task. Future studies should address this limitation.

3.4 Conclusions

Taken together, our findings provide initial support for the validity of our modified EEfRT as a measure of approach motivation and suggest that a low dose of sulpiride reduces/impairs approach motivation as measured with the modified EEfRT. As this result was contradictory to our expectations, future studies should consider investigating various possible moderating factors (study design, incentive context, etc.) and limiting factors (global effect of sulpiride and impact of motoric abilities). Nonetheless, the associations between task performance and both extraversion and trait BAS provide tentative support for the hypothesized link between these traits and approach motivation. The unexpected lack of a moderating effect of extraversion on the effects of sulpiride observed in several previous studies (e.g., Wacker, 2018; Wacker et al., 2013) encourages further work aimed at identifying the relevant boundary conditions and further elucidating the hypothesized dopaminergic mechanisms underlying stable individual differences in approach motivation. Future studies should also further improve assessment of participants' motoric abilities to better delineate approach motivation and motoric abilities within the modified EEfRT, which have shown to strongly impact performance on this task.

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C: Studien 3 + 4: Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT)

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Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT)

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Abstract:	The Effort-Expenditure for Reward Task (EEfRT) has gained validity evidence from various studies. However, various modifications have been applied to the original version, which have never been compared systematically. In Study 1 we tested 120 healthy participants to directly compare two versions of the EEfRT. In Study 2 we tested a larger sample of 394 healthy participants to further examine the original EEfRT. We replicated the reliability of both task versions. However, trait BAS and trait anticipatory pleasure correlated positively with only some task performance parameters in Study 1 that did not replicate for the original EEfRT in Study 2. Our results indicate complex and sometimes inconsistent relations between different personality traits, task properties, reward attributes and study design.

Cover Letter

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September 18, 2020

Dear Editor,

Enclosed you will find a manuscript entitled “Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT)”, which we wish to be considered for publication in the *Journal of Research in Personality.*

With this paper we respond to a recent call to take a critical look at the quality of psychological measures (Flake & Fried, in press) by examining different versions of the widely used Effort-Expenditure for Reward Task (EEfRT). This task was originally designed to test participants willingness to exert physical effort in order to gain monetary rewards and is considered a behavioral measure of approach motivation. However, a thorough examination of the tasks reliability and validity is still missing.

The paper features two studies. In Study 1 we tested 120 healthy participants with two versions of the EEfRT within one experimental design and directly compared the reliability and validity of both task versions. In Study 2 we tested a larger sample of 394 healthy participants with the original EEfRT. The larger sample was tested to detect potentially smaller correlations. We replicated the reliability of both task versions and the validity of basic task variables across both studies. However, personality correlated positively with only some task performance parameters in Study 1 that did not replicate for the original EEfRT in Study 2.

So far only very few studies investigated which effects modifications to the original EEfRT cause regarding its reliability and validity. In addition, both studies document that the linkage between behavioral task performance and self-reported personality should be investigated in a more complex manner, taking study design and task parameters into account. Beyond the more obvious implications for future work using the EEfRT, our findings illustrate that low replicability of performance in laboratory tasks with personality traits may in part be due to underappreciated psychometric weaknesses of the tasks used.

Please have all correspondence addressed to me at the above address. The manuscript is original, is not under consideration, and has not been previously published elsewhere. There were no commercial or financial involvements relevant to this study. The manuscript has been approved by all authors. Finally, informed consent was obtained from each participant, and participants’ rights were fully protected.

We look forward to hearing from the Journal.

Sincerely,

Hanno Andreas Ohmann, M.Sc.

Examining the reliability and validity of two versions of the Effort-Expenditure for Reward Task (EEfRT)

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Short title: Validation of two versions of the EEfRT

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Mr. Ohmann has nothing to disclose.

*HAO contributed to study conceptualization, data collection, data preparation, data analysis and manuscript writing. NK contributed to data preparation, data analysis and editing of the manuscript. JW contributed to study conceptualization and editing of the manuscript.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

- The original EEfRT and a modified version of the task show overall good reliability.
- Both tasks versions correlate significantly but correlations are small.
- Previously found validating results linking task performance to self-reported personality couldn’t be replicated.
- Results hint at a complex interaction of personality traits, task properties, reward attributes and study design.

Keywords: Reliability; Validity; EEfRT; Approach Motivation; BAS

Abstract

The Effort-Expenditure for Reward Task (EEfRT) has gained validity evidence from various studies. However, various modifications have been applied to the original version, which have never been compared systematically. In Study 1 we tested 120 healthy participants to directly compare two versions of the EEfRT. In Study 2 we tested a larger sample of 394 healthy participants to further examine the original EEfRT. We replicated the reliability of both task versions. However, trait BAS and trait anticipatory pleasure correlated positively with only some task performance parameters in Study 1 that did not replicate for the original EEfRT in Study 2. Our results indicate complex and sometimes inconsistent relations between different personality traits, task properties, reward attributes and study design.

1. Introduction

Harmon-Jones et al. (2013, p. 291) define approach motivation as "the impulse to go toward", which is based on internal state or trait - related processes and initiates behavior which is often (but not necessarily) associated with reaching specific goals. Approach motivation can therefore be seen as one of the main drives of human behavior (Lazrarus, 1991a, 199b). The field of personality research related to approach motivation is often linked to Gray`s model of personality, which accumulated in his Reinforcement Sensitivity Theory (RST; Gray, 1990; Corr, 2001). A variety of self-report measures are available for the assessment of personality traits related to sensitivity to rewards and punishment, ranging from the commonly used BIS / BAS scales (Carver & White, 1994) to the Temporal Experience of Pleasure Scale (TEPS Gard et al., 2006) measuring anticipatory pleasure and consummatory pleasure. However, linking self-reported personality traits to behavioral measurements often leads to rather small correlations (Mischel, 1969,2009). Dang et al. (2020) suggest that this might be a result of the poor reliability of many behavioral measures and the different response processes of these two types of measurement. Moreover, multiple behavioral tasks to measure approach motivation have been developed in a post-hoc manner and / or are based on animal models (e.g. Salamone et al., 1994). A majority of these tasks utilizes physical effort, which participants have to invest to gain rewards. Various kind of physical efforts have been utilized. For example, hand-grip tasks assess willingness to expend effort by force exerted on the grip (Clery-Melin et al., 2011; Kurniawan et al., 2010; Reddy et al., 2015); Such tasks are often adapted to a model based on effort discounting, which allows to measure the extent to which the need for effort reduces preference for a given reward (Hartmann, Hager, Reimann et al., 2015; Hartmann, Hager, Tobler, et al., 2013; Klein-Flugge et al., 2015). Similar tasks use button or lever pressing in a progressive ratio format (Hershenberg et al., 2016; Lane et al., 2005; Strauss et al., 2016). Unfortunately, the majority of these tasks lack a comprehensive test of their reliability and validity. Comparing the psychometric properties of

five different effort-based decision-making tasks in a clinical sample (schizophrenic patients) and a healthy control sample, the Effort Expenditure for Rewards Task (EEfRT; Treadway et al., 2009) exceeded the reliability of four other tasks (Reddy et al., 2015; Horan et al., 2015), making it a promising tool to investigate approach motivation.

The EEfRT is based on a concurrent choice paradigm developed by Salamone et al. (1994) to explore effort-based decision making in rodents. The original EEfRT measures individual differences in human reward motivation by having participants decide between high cost/high reward (hard task, many clicks needed) and low cost/low reward (easy task, few clicks needed) behavioral options. The tendency to choose the hard task rather than the easy task has been shown to be associated with high levels of approach motivation, as measured e.g. via personality questionnaires (Geaney et al., 2015). Precisely, trait BAS and trait anticipatory pleasure correlated positively with the percentage of hard-task-choices in trials with a low probability of rewards attainment in the original EEfRT. This indicates that higher approach motivation measured by questionnaires is related to concrete behavior directed at gaining rewards in the EEfRT. Recently, these findings were replicated using a modified version of EEfRT, showing that trait extraversion and trait BAS correlated positively with the mean number of clicks participants exerted in trials with a low probability of reward attainment (Ohmann et al., 2020). However, Horan et al. (2015), Anand et al. (2016) as well as Kaack et al. (2020) were not able to replicate these correlations, raising questions about the existence of such associations. According to Smillie (2008) trait behavioral activation system (BAS) sensitivity should be predominantly related to reward sensitivity, while trait behavioral inhibition system (BIS) sensitivity should be predominantly related to punishment sensitivity. One would thus expect relatively specific associations between behavior in the task and personality traits. The EEfRT has gained further support for its validity from various studies (see Table 1). Healthy participants' preference for the hard task has i.e. been shown to correlate with lower scores on negative affect, depressive

symptoms, and anhedonia (Treadway et al, 2009). Furthermore, it was shown that left frontal anodal transcranial direct current stimulation over the dorsolateral prefrontal cortex increased participants' willingness to choose the hard task depending on reward attributes (Ohmann et al., 2018), which is in line with models associating left frontal brain activity with approach motivation (Harmon-Jones & Gable, 2017; Rutherford & Lindell, 2011). Wardle et al. (2011) were the first to show that the EEfRT is also sensitive to pharmacological manipulation of DA, as d-amphetamine increased participants overall effort allocation. Furthermore, a low dosage of the D2 receptor blocker sulpiride, which is e.g., used in patients with depression and is believed to increase approach motivation, decreased participants willingness to exert clicks in a modified version of the EEfRT (Ohmann et al., 2020). Probably the most convincing evidence for the validity of the EEfRT comes from patients suffering from impaired approach motivation: Patients with schizophrenia (Fervaha et al., 2013; Barch et al., 2014; McCarthy et al., 2016), first-episode psychosis (Chang et al., 2019), depression (Treadway et al., 2012; Yang et al., 2014) and autism (Damiano et al., 2012) were less willing to choose the hard task as compared to healthy controls. Furthermore, the number of hard-task-choices was found to be negatively correlated with the severity of anhedonic symptoms in patients with schizophrenia (e.g. Barch et al., 2014) as well as in patients with depression (e.g. Yang et al., 2014). Nguyen et al. (2018) found in a large healthy sample of parents and their children that psychopathic symptoms also correlated with reduced effort allocation within the EEfRT. The EEfRT has also gained evidence on a neurophysiological level, as it has shown to be related to left-frontal cortical asymmetry in resting state as well as while task performance (Hughes et al, 2015; Kaack et al., 2020), which is believed to be a neural signature of approach motivation. Moreover, Huang et al. (2016) found that the percentage of hard-task-choices was directly linked to the activity of the NAcc, which is a key structure of the human reward circuit, in both patients with schizophrenia and healthy participants. Overall, the literature shows intriguing support for the validity of the EEfRT.

However, there are also various limiting aspects (see Table 1). First, the number of studies reporting a significant link between the behavioral measurements within the EEfRT and self-ascribed personality traits related to approach motivation is still small, albeit many studies refer to this link to prove the validity of the EEfRT. Second, the number of participants in studies which used the EEfRT has often been relatively small, resulting in low statistical power to detect effects sizes that can be expected in individual difference research (Gignac & Szodorai, 2016). Together with concerns about the replicability of psychological findings in general (Open Science Collaboration, 2015) as well as literatures relevant to this manuscript (e.g., trait approach motivation – frontal asymmetry link; Kuper et al., 2019), this highlights the risk of false positive results in previous studies. Third, the original EEfRT has been shown to be partly related to individual strategic behavior, which is not related to participants actual approach motivation (Ohmann, Kuper, Wacker, 2018). The modified version of the EEfRT (Ohmann, Kuper & Wacker, 2020) seeks to eliminate this limitation of the original task, but so far lacks data to document its own reliability and validity. Fourth, seemingly small differences in task properties and administration could have a great impact on task behavior. Despite this, several studies already modified the original EEfRT to fit different experimental settings (see Table 1).

Table 1. A review of selected studies using the EEfRT: Modifications, reliability and validity (chronological order).

Study	**N**	**Main dependent variable(s)**	**Main modifications applied to the original task**	**Modications tested against original?**	**Reliability reported?**	**Validity test**
Treadway et al. (2009)	61	HTC	-	-	No	Self-report measures (Anhedonia, depression)
Wardle et al. (2011)	17	HTC	Repeated measure design	No	No	Effects of d-amphetamine
Damiano et al. (2012)	58	HTC, response change	Removed time-limit for task choice	No	No	Patients with ASD (n= 20) VS healthy controls (n = 38)
Wardle et al. (2012)	23	HTC, response speed	Practice session, repeated measure	No	No	Effects of caffeine
Fervaha et al. (2013)	32	HTC	Individual calibration of required clicks	No	No	Patients with SCZ (n= 16) VS healthy controls (n = 16)
Barch et al. (2014)	98	HTC	Removed low probability trials	No	No	Patients with SCZ (n= 59) VS healthy controls (n = 39); self-report measures (anhedonia, depression)
Yang et al. (2014) -study 1	99	HTC	Reduced number of required clicks; fixed the possible monetary rewards	No	No	high BDI-score (n =43) VS low BDI score (n =56); self-report measures (anhedonia; pleasure)
– study 2	87	HTC	""	No	No	Patients with MDD (n = 41) VS remitted MDD (n= 41)

Note. ASD = Autism spectrum disorder; BAS = Behavioral Activation System; BIS= Behavioral Inhibition System BDI = Beck Depression Inventory; BMI = Body-mass-index; HTC = Hard-task-choices; MDD = major depressive disorder; SCZ = schizophrenia

Table 1 (Continuation). A review of selected studies using the EEfRT: Modifications, reliability and validity (chronological order).

Study	N	Main dependent variable(s)	Main modifications applied to the original task	Modifications tested against original?	Reliability reported?	Validity test
Hughes et al. (2014)	51	HTC	Paid 10% of total winnings	No	No	Effects of frontal asymmetry (resting state)
Geaney et al. (2015)	97	HTC	Mood induction; paid 10% of total winnings	No	No	Self-report measures (anhedonia, pleasure, BAS)
Gilman et al. (2015)	50	HTC; reaction time	Pictures of peers (social influence)	No	No	Effects of different social influence conditions
Reddy et al. (2015)	134	Reward sensitivity	Repeated measure; individual calibration of required clicks; no low probability trials	No	**Yes (retest)**	Patients with SCZ (n= 94) VS healthy controls (n = 40); comparison with four other tasks
Horan et al. (2015)	“	“	“	“	"	Self-report measures (SCZ symptoms; motivation; BIS/BAS)
Hughes et al. (2017)	128	HTC	Repeated-measure-design; shorter task selection (3s)	No	No	Abstinent smoker (n = 61) VS former smoker (n = 67); self-reported reward enjoyment
Johnson et al. (2017)	50	HTC	Fixed probability (50%), Three bonus trials added (no effort needed)	No	No	Patients with remitted bipolar disorder; self-reported life ambitions
Racine et al. (2018)	63	HTC	Food portions instead of monetary reward	No	No	Comparison of participants with different degree of Binge-eating symptoms; BMI

Note. ASD = Autism spectrum disorder; BAS = Behavioral Activation System; BIS= Behavioral Inhibition System BDI = Beck Depression Inventory; BMI = Body-mass-index; HTC = Hard-task-choices; MDD = major depressive disorder; SCZ = schizophrenia

Table 1 (Continuation). A review of selected studies using the EEfRT: Modifications, reliability and validity (chronological order).

Study	N	Main dependent variable(s)	Main modifications applied to the original task	Modifications tested against original?	Reliability reported?	Validity test
Lopez-Gamundi & Wardle (2018)	60	HTC	Cognitive effort version	**Yes**	No	Comparison of cognitive VS original version
Nguyen et al. (2018)	2259	Reward sensitivity	No probabilities of reward attainment for kids	No	No	Comparison of parents (n= 1044) and children (n= 1215) for psychopathic symptoms
Ohmann et al. (2018)	60	HTC	Repeated measure design; paid 5% of the total winnings	No	No	Effects of anodal tDCS stimulation
Byrne & Ghaiumy Anaraky (2019)	94	HTC	Addition of "loose" trials; temporal delay after easy trials	No	No	Comparison of older (n= 46) and younger adults (n= 48)
Ohmann et al. (2020)	203	Button presses	No task selection, increasing monetary win with each click	No	**Yes (split-half)**	Effects of sulpiride; Self-report measures (Big Five; BIS/BAS)
Kaack et al. (2020)	49	HTC	Additional "offer"- screen (5s) prior to choice screen; best performing student would receive $100 grocery store voucher	No	No	Effects of frontal asymmetry (resting and task states); Self-report measures (BIS/BAS)

Note. ASD = Autism spectrum disorder; BAS = Behavioral Activation System; BIS= Behavioral Inhibition System BDI = Beck Depression Inventory; BMI = Body-mass-index; HTC = Hard-task-choices; MDD = major depressive disorder; SCZ = schizophrenia

Just to name a few examples: Yang et al. (2014) reduced the number of required clicks and fixed the possible monetary rewards to reduce the complexity of the task for depressive patients. This design was also used by Huang et al. (2016) to make the EEfRT suitable for functional brain imaging. Barch et al. (2014) completely removed the low probability of reward attainment category, Damiano et al. (2012) removed the time limit when participants select either the easy or the hard task, Fervaha et al., 2013) calculated an individual number of required clicks before the actual task based on motoric abilities, and Byrne & Ghaiumy Anaraky (2019) introduced "loss trials", in which choosing the easy task leads to potentially higher monetary loss compared to the hard task. Other authors exchanged the monetary rewards of the EEfRT, e.g. by using food portions in a study with patients suffering from binge-eating (Racine et al., 2018), or added a social influence aspect while participants chose between the easy and hard task of the EEfRT by adding pictures of "peers" and their respective choices (Gilman et al., 2015). Despite these various modifications applied to the EEfRT so far, surprisingly little is known about the effect of such modifications as almost no study directly compared different versions of the EEfRT within one experimental design. A commendable exemption from this is a study by Lopez-Gamundi & Wardle (2018), who compared the original EEfRT to a modification which uses cognitive effort (set-switching-task; C-EEfRT) instead of the physical effort within the original task (clicks). Although participants perceived the C-EEfRT as more difficult, participants did choose the hard-task more often compared to the original EEfRT. Furthermore, the relationship between the effort allocation within both task versions was only moderate, indicating distinct processes for both kind of efforts when participants decide to allocate effort to gain a possible reward.

Bearing these limitations in mind, we here seek to analyze the reliability and validity of the original EEfRT and a modified EEfRT in 2 different study designs and try to deepen the understanding of the link between self-ascribed personality traits and behavioral task measures. Study 1 aims at directly comparing the validity and reliability of two versions of

the EEfRT. Study 2 aims to replicate the reliability and validity of the original EEfRT by making use of a large sample to further increase statistical power.

1.1 Hypotheses

1.1.1 Reliability of the EEfRT

Based on the promising results regarding the reliability found in previous studies for the original EEfRT (Reddy et al., 2015; Horan et al., 2015) and likewise promising results for the reliability of the modified EEfRT (Ohmann et al., 2020), we expected both versions of the task to show overall good (Rel > .80) reliability in both studies. We further examined the internal consistency of all questionnaire measures used in both studies.

1.1.2 Validity of Basic Task Variables

In line with previous research, we expected the reward attributes (reward magnitude and probability of reward attainment) to be positive predictors of the percentage of hard-task-choices (original EEfRT) and mean number of clicks (modified EEfRT), whereas we expected trial number (i.e., an indicator of fatigue) to be a negative predictor of the percentage of hard-task-choices (original EEfRT) and mean number of clicks (modified EEfRT). GEE models (generalized estimating equations, Liang, 1986; Zeger & Liang, 1986) have been the main analysis strategy for the examination of basic task variables in previous work on the EEfRT (i.e. Treadway, et al, 2009; Geaney et al., 2015; Ohmann et al., 2020). Therefore, we also applied GEE models to test for the effects of the above-mentioned basic task variables.

1.1.3 Personality Correlations

As Gignac & Szodorai (2016) stated, correlations of $r = .30$ should be considered as rather high correlations in the field of individual differences. Applying these standards, previous studies using the original EEfRT (Geaney et al., 2015) as well as the modified version of the EEfRT (Ohmann et al., 2020) found medium to large correlations for the percentage of hard-task-choices (original EEfRT) and the mean number of clicks (modified EEfRT) in trials with low probability of reward attainment with trait BAS and trait anticipatory pleasure. We seek to replicate these correlations in both studies. Furthermore, as some studies using the EEfRT focused on the impact of reward magnitude, as well as the differences between low and high reward trials (Reddy et al., 2015; Horan et al., 2015), indicating "reward sensitivity", we exploratorily analyzed the correlations between traits with the percentage of hard-task-choices (original EEfRT) and mean number of clicks (modified EEfRT) depending on reward magnitude. Therefore, we examined the correlations between traits and task performance in all probability of reward attainment categories as well as in all reward magnitude categories and difference scores between these trial categories in an exploratory fashion. To evaluate the discriminant validity of both tasks, we further tested for the associations with distinct constructs, which we expected to not correlate with effort allocation on both tasks - namely risk-taking and impulsivity.

1.1.4 Secondary Analysis

As Study 1 includes both versions of the EEfRT in one experimental design, we seek to estimate the correlations between both versions in an exploratory fashion. As there are no previous studies to base our hypothesis on, we only hypothesize a significant positive correlation between both versions, as both tasks should measure the same construct: approach motivation. We further analyzed participants' self-reported strategy usage and motivation and their linkage to task performance in Study 1 to further test the validity of both task versions.

2. Methods

2.1 Experiment 1

2.1.1 Participants

We recruited physically and psychologically healthy participants (78,3% female) aged 18 – 35 (M = 24,97; SD = 4,14) using online notice boards and flyers at a local university. Out of 125 recruited participants, 5 had to be excluded for different reasons (1 participant was not able to understand the instructions; 2 participants did not understand the task; 2 participants had missing values due to technical failure). Thus, the final sample consisted of 120 participants. In line with previous studies (Geaney et al., 2015; Ohmann et al., 2020), we expected correlations around ρ = .30 (i.e., large correlations according to Gignac & Szodorai, 2016). As intended, statistical power was therefore >.80 (exact 1-β = .92) to detect correlations of ρ = .30 (α = .05). Participants received monetary compensation (10€ per hour) and were told that they could gain additional money based on their collected rewards from both versions of the EEfRT (5% of the virtually collected money) and the BART (one cent per 4 pumps in successful trials) which was paid to participants at the end of the study. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The study has been approved by the local Ethics Committee. Exclusion criteria comprised the intake of any kind of prescribed medication over the last three months, the consumption of illegal drugs over the last four weeks, neurological or medical conditions, and the presence of any mental disorders (in particular affective,- somatoform,- psychotic,- anxiety,- eating,- and adaptive disorders, as well as mental disorders triggered by drug abuse).

2.1.2 Randomization

As we intended to compare both versions of the EEfRT (original / modified) and their relation to measures of personality traits and risk-taking behavior, we randomized the order of both tasks in a counterbalanced fashion to ensure that the order of both tasks did not influence effort allocation. Participants were randomly assigned to one of both conditions at the start of part two of our study.

2.1.3 Procedure

Participants who fit the inclusion criteria were provided with information about the study via email. After giving their informed consent, participants received an individual link to the first part of the study. The first part of the study comprised an online-survey lasting about 30 minutes, in which participants filled out a small series of questionnaires, including demographic information and German versions of the BIS/BAS scales (Carver & White, 1994; Strobel et al., 2001), the TEPS (Gard et al., 2006), and the UPPS (Whiteside & Lynam, 2001; Schmidt et al., 2008). Participants who completed the first part of the study were invited into our lab. After arriving at our lab, participants completed a series of computer tasks lasting about 60 minutes. All participants started by completing a test of their motoric abilities. Participants then completed either the original or the modified version of the EEfRT according to the assigned condition. Afterwards, they completed the BART (Balloon Analogue Risk Task, Lejuez et al., 2002, Pleskac et al., ,2008). This was followed by another test of their motoric abilities and the complementary version of the EEfRT, which participants did not complete before. Finally, participants completed a small set of questions, including questions about aspects that might have influenced their effort allocation within each version of the task (reward magnitude, probability of reward, fatigue, resting one's fingers) and their motivation to earn additional money throughout the whole study using five-point Likert-scales ranging from "not at all"(1) to "a lot"(5).

2.1.4 Original EEfRT

We used a translated (German) version of the EEfRT (Treadway et al., 2009), which was programmed using Presentation software 17.1 (Neurobehavioral Systems Inc, San Francisco). Every participant completed one 15–minute block of the EEfRT with their dominant hand. Participants were instructed to win as much virtual money as possible throughout the block. In short, participants need to choose between an easy, low-reward task and a hard, high-reward task in every trial (see figure 1 for a schematic illustration). The reward for the easy task is fixed to 1 € while the reward for the hard task is variable (ranging between 1.21 € and 4.30 €). To further manipulate the value of each reward, the probability of reward attainment also varies [either 12% (low), 50% (middle) or 88% (high)], which is presented at the start of each trial alongside the reward values. The easy task requires participants to press the space button 30 times ("clicks") in 7 seconds with their index finger. The hard task requires participants to press the space button 100 times ("clicks") in 21 seconds with their pinkie finger. While pressing the spacebar, a visually presented white bar gradually fills up with red color. After each trial, the participants are informed about the amount of money they won during the trial. The order of trials, as well as the probability of reward attainment and the reward magnitudes are not randomized between participants, but pre-assigned for each trial. This is done to rule out random feedback differences between participants.

2.1.5 BART

To test participants` risk-taking behavior, we also assessed the BART (Lejuez et al., 2002, Pleskac et al., ,2008). In this task, participants are presented a picture of a balloon, and instructed to inflate this balloon. Inflating the balloon increases the size of the balloon on screen and the associated reward. However, overinflating the balloon would result in the balloon bursting accompanied by an aversive auditory sound. Bursting of the balloon causes the participant to lose the entire reward of that trial. Each of 30 balloons have a different

predetermined bursting point, on a scale of 1 to 128 (pumps). Participants are instructed that the average number of inflations that causes the balloon to burst is 64 and that they would gain one Cent per 4 pumps, only in successful trials (balloon did not burst). In line with previous studies, we used the automatic response procedure of the BART (Pleskac et al., 2008, Janssen et al., 2015), in which the participants could immediately select the intended number of pumps for that specific trial and receive immediate feedback as they watch the balloon inflating. Also, risk taking scores were calculated as the mean of the number of pumps across all balloons regardless of the burst event (Pleskac et al.,2008), unlike in the original BART (Lejuez et al., 2002).

2.1.6 Modified EEfRT

Additionally, we used a modified version of the original EEfRT (Treadway et al., 2009), which was programmed using Presentation software 17.1 (Neurobehavioral Systems Inc, San Francisco) and has been used in one previous study (Ohmann et al., 2020). Ohmann et al. (2018) found that using the original EEfRT comes with a major downside: At least some participants understand that choosing the hard task is often lowering the possible overall monetary gain as the hard task takes almost 3 times as long as the easy task. Hence, at least some participants' choices are partly based on a strategic decision and less on approach motivation per se. To overcome this downside, the original EEfRT was modified. First, the number of trials (2 blocks x 15 trials = 30 trials) and the duration of each trial (= 20 seconds) was fixed. Participants use their right hand for one block and their left hand for the other block, the order of both blocks was randomized. Second, the original choice-paradigm was changed. Participants no longer choose between an easy and a hard task. As in the original task, the value of each reward varies, and participants are informed about this at the start of each trial. But instead of presenting specific reward magnitudes, participants are now presented with a reward magnitude per click (1 /2 / 3 / 4 / 5 cents per click). Thus, participants are able to increase the total possible monetary gain in each trial with each click. In

accordance with the original task design, the probability of reward attainment also varied [either 12% (low), 50% (middle) or 88% (high)], which is presented at the start of each trial alongside the reward value per click. Participants were instructed to win as much virtual money as possible throughout the task, however they were free to choose the amount of effort they exerted in each trial. Critically, the only way to increase the possible monetary gain is to increase the number of clicks in each trial. The task itself is designed close to the original EEfRT but comes with some modifications to prevent the use of strategies (see figure 2). While pressing the spacebar, a visually presented red bar gradually grows. A scale (€) was implemented, so that the participants can always see how much their button-presses ("clicks") increase their possible monetary gain. Furthermore, we the information on the reward magnitude per click and the probability of reward attainment is presented throughout the whole trial alongside a countdown (20 seconds) to increase participants' awareness of these parameters. After each trial, participants are informed about the amount of money they won during the trial. The order of trials, as well as the probability of reward attainment and the reward magnitudes per click are not randomized between participants, but pre-assigned for each trial. This is done to rule out random feedback differences between participants.

2.1.7 Motoric Abilities

Participants with greater motoric ability exert more clicks throughout the modified version of the EEfRT (Ohmann et al., 2020) and studies calibrating an individual number of clicks to succeed within the original EEfRT suggest that participants with higher motoric abilities might also choose the hard task more often in the original version (Fervaha et al., 2013; Reddy et al., 2015) , which does not reflect their actual approach motivation. Therefore, we included 10 motoric trials to test participants' motoric abilities before each version of the EEfRT. Within these motoric trials, participants were instructed to press the spacebar as often as possible within 20 seconds. Critically, participants were not able to gain any rewards in these trials and visual feedback was reduced to a countdown and a display of the number of

clicks they exerted. Participants' individual motoric abilities were operationalized as maximal clicks in motoric trials (MaxMot) and included in our statistical models.

2.1.8 Data Analysis

Aggregated data were further analyzed using the SPSS 26.0 software* (Chicago, IL, USA). To test for the effects of basic predictors on the percentage of hard-task-choices (original EEfRT) and on the mean number of clicks (modified EEfRT), we used GEEs. GEEs are marginal models that allow for robust parameter estimation despite correlated residuals, e.g., due to the clustering of trials within participants (Liang, 1986; Zeger & Liang, 1986). Models were fit using an independent working correlation matrix. Crucially, they are consistent even when the correlation matrix for the residuals is specified incorrectly. All GEE models included the factors trial number, probability (categorical), reward magnitude, and the interaction of probability x reward magnitude (often referred to as "expected value"). Moreover, participants' individual motoric abilities were included in all GEE models. Pearson correlations were computed between trait personality variables (BIS/BAS/TEPS/UPPS), the number of pumps within the BART, the percentage of hard-task-choices within the original EEfRT, and the mean number of clicks within the modified EEfRT separately for each probability of reward attainment category (low/medium/high), for each reward magnitude category (low/medium/high), as well as for difference scores between these categories. Within the original EEfRT we formed these categories in line with previous studies (i.e. Hughes et al., 2015); low reward magnitude: <2,30 Euro, medium reward magnitude: 2,31-3,29 Euro, high reward magnitude: >3,30 Euro. For the modified EEfRT we calculated analogue categories: Low reward magnitude: 1 or 2 Cent per click, medium reward magnitude: 3 cent per click, high reward magnitude: 4 or 5 Cent per click. Further Pearson correlations were calculated between both versions of the EEfRT for each probability of reward attainment category, each reward magnitude category, as well as between both versions of the EEfRT and follow-up questions regarding individual strategies and motivation. Datasets and syntax can

be found at: https://osf.io/35k2w/?view_only=1f315859028c471787a96e153f5ac43a.

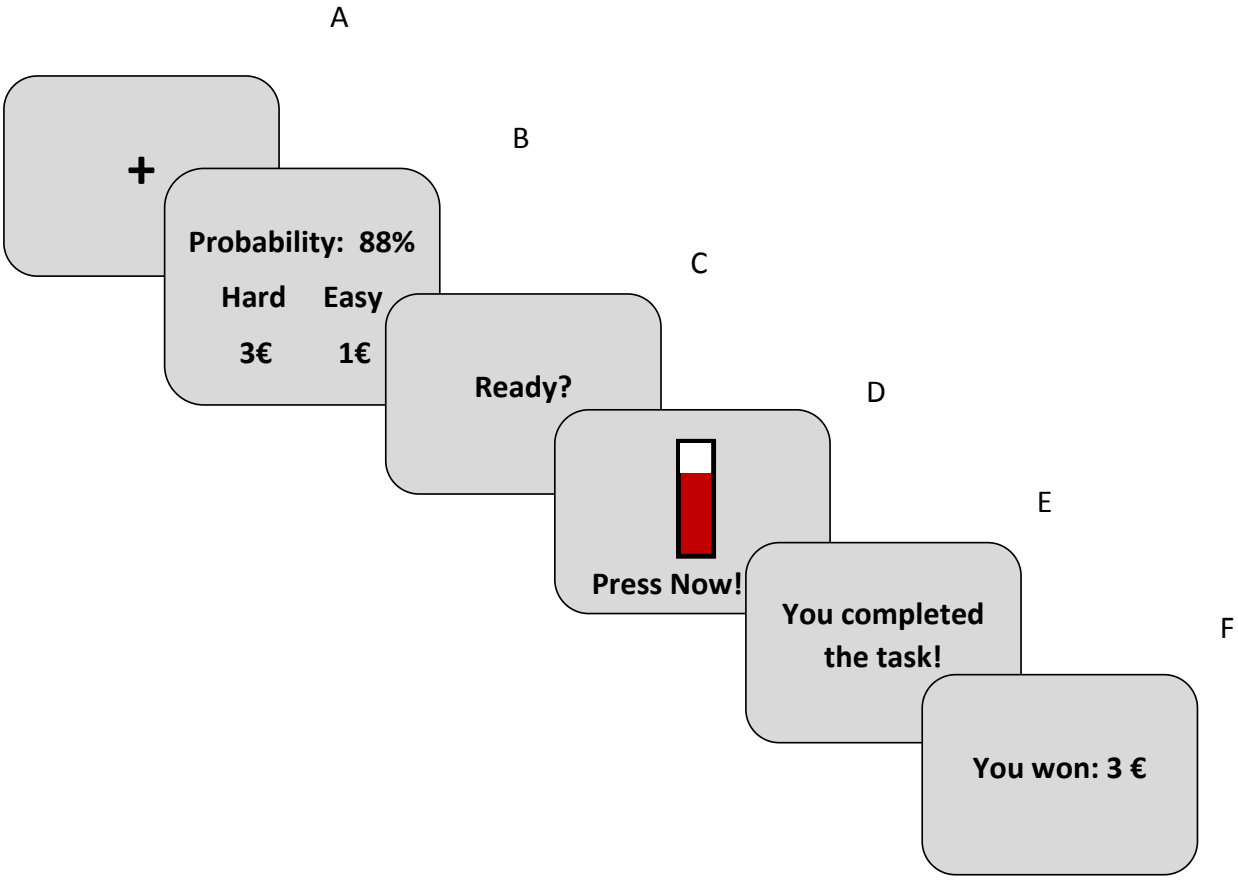

Figure 1. Schematic illustration of one trial on the original EEfRT. A fixation cross (1s, A) is followed by a screen showing probability of reward attainment and reward magnitude for the easy and the hard task (B), lasting until the participant made a choice which task to complete, but no longer than 5s. Then, after a ready – screen (1s, C) the main screen for the trial showing a red bar that fills with each click is presented until the task is completed or until the trial time is over (D). Finally, task completion is signaled (2 s, E) and a feedback screen shows the amount of money won (2s, F).

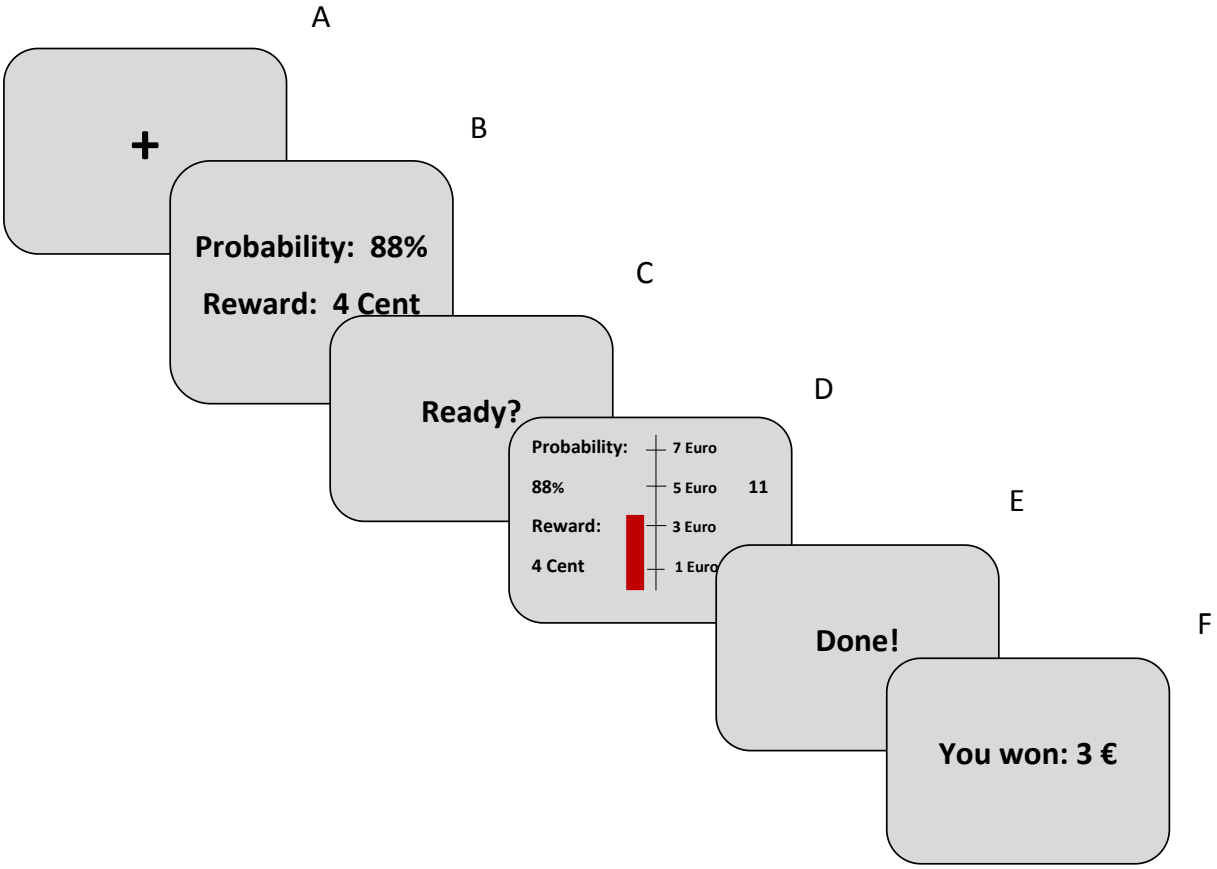

Figure 2. Schematic illustration of one trial of the modified EEfRT. A fixation cross (1s, A) is followed by a screen showing probability of reward attainment and reward magnitude per click for 3s (B). Then, after a ready – screen (1s, C), the main screen for the trial showing a red bar that grows with each click is presented alongside a scale, indicating the current monetary gain and a countdown (20s, D). Finally, task completion is signaled (1,5s, E) and a feedback screen shows the amount of money won (2s, F).

2.2 Experiment 2

2.2.1 Participants

We recruited physically and psychologically healthy, right-handed participants (68.2% female) aged 18 – 50 (M = 25.74; SD = 5.37) using online notice boards and flyers at various universities. Out of 409 recruited participants, 15 had to be excluded for different reasons (11 participants consumed illegal drugs or hormones within the last 12 months, 1 subject already knew the EEfRT task, 1 subject was ambidexter,1 subject had missing values for the UPPS, and for 1 subject it was not possible to collect a blood sample). Thus, the final sample consisted of 394 participants. In accordance with Gignac & Szodorai (2016) we applied a more conservative criterium than in Study 1 and expected only medium-sized correlations. As intended, statistical power was therefore >.80 (exact 1-β = .98) to detect correlations of ρ = .20 (α = .05). Participants received monetary compensation (10€ per hour) and were told that they could gain additional money based on their collected rewards from the original EEfRT (5% of the virtually collected money). At the end of the study, all participants received 5€ to ensure equity. This amount was always higher than the 5% of the virtually collected money. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The study has been approved by the local Ethics Committee. Exclusion criteria comprised the regular intake of any kind of prescribed medication, consumption of illegal drugs over the last 12 month, neurological or medical conditions and the presence of any mental disorders (in particular affective,- somatoform,- psychotic,- anxiety,- eating,- and adaptive disorders, as well as mental disorders triggered by drug abuse), high consumption of alcohol (more than 15 glasses per week), nicotine (more than 15 cigarettes per week) or caffeine (more than 4 cups per day), and pregnancy (tested onside).

2.2.2 Procedure

As the original EEfRT and both relevant questionnaires (BIS/BAS, UPPS) were deployed as part of a larger study we will focus only on the most relevant information. A complete description of the procedure will be provided elsewhere. The order of tasks and questionnaires was not randomized and in contrast to Study 1, no motoric trials were included. Participants who fit the inclusion criteria were invited into the lab once. After arriving at the lab and giving their informed consent, participants completed a large series of questionnaires, including the German BIS/BAS (Carver & White, 1994; Strobel et al., 2001) and the UPPS (Whiteside & Lynam, 2001; Schmidt et al., 2008), as well as a series of computer tasks, including the original EEfRT (Treadway et al., 2009). The overall experiment lasted for about 4,5 hours. The EEfRT took place approximately 4 hours after the start of the experiment.

2.2.3 Original EEfRT

The procedure of the original EEfRT was identical to experiment 1 (see 2.1.4 and figure 1).

2.2.4 Data Analysis

Statistical analysis for the original EEfRT was identical to experiment 1 (see 2.1.8), with the following exception: As no motoric trials were included, individual motoric abilities were removed as a factor from the GEE model. In accordance with Study 1, Pearson correlations were computed between trait personality variables (BIS/BAS/ UPPS) and the percentage of hard-task-choices within the original EEfRT for each probability of reward attainment (low/medium/high) and each category of reward magnitude (low/medium/high), as well as difference scores between these categories. Datasets and syntax can be found at: https://osf.io/35k2w/?view_only=1f315859028c471787a96e153f5ac43a.

3. Results

3.1 Reliability

We examined the internal consistency of all questionnaires in both studies by estimating Cronbach‘s Alpha. Most questionnaires showed moderate to good internal consistency (see Table 2). However, two subscales of the BIS/BAS scales (Fun Seeking; α = 0.56 / Reward Responsiveness; α = 0.53) showed insufficient reliability in Study 2. We then calculated the reliability of the EEfRT by estimating the split-half reliability and applying Spearman-Brown corrections to the resulting estimates. Note however, as we introduced motoric trials within Study 1, we compared both reliabilities (adjusted for motoric abilities and non-adjusted, see Table 2). Therefore, we calculated the reliability of the percentage of hard-task-choices after residualizing for motoric abilities (operationalized as maximal clicks in motoric trials; MaxMot). The overall HTCs and clicks showed overall robust reliability in both studies, within the original EEfRT in Study 1 (Rel =.90; Adj. Rel = .91) and in Study 2 (Rel. = .87) and within the modified EEfRT in Study 1 (Rel = .96; Adj Rel. = .92)

When separately analyzing the data for each probability and reward magnitude category, split-half reliabilities ranged between Rel = .73 and .97 over both studies and task versions. Overall, both versions of the EEfRT showed good reliability and the adjustment for motoric abilities in Study 1 impacted the reliability of the EEfRT only slightly.

Table 2. Internal consistencies and reliabilities for questionnaires and both versions of the EEfRT in Study 1 and 2.

	Study 1	Study 2
Questionnaires		
BAS	$\alpha = 0.79$	$\alpha = 0.74$
BAS Fun Seeking	$\alpha = 0.67$	$\alpha = 0.56$
BAS Reward Responsiveness	$\alpha = 0.70$	$\alpha = 0.53$
BAS Drive	$\alpha = 0.74$	$\alpha = 0.75$
BIS	$\alpha = 0.78$	$\alpha = 0.79$
TEPS Anticipatory	$\alpha = 0.67$	-
TEPS Consummatory	$\alpha = 0.70$	-
UPPS Urgency	$\alpha = 0.86$	$\alpha = 0.84$
UPPS Premeditation	$\alpha = 0.78$	$\alpha = 0.77$
UPPS Perseverance	$\alpha = 0.83$	$\alpha = 0.82$
UPPS Sensation Seeking	$\alpha = 0.84$	$\alpha = 0.83$
Original EEfRT task		
HTCs	Rel =.90 / Rel_{adj} =.91	Rel =.87
Low Probability HTCs	Rel =.84 / Rel_{adj} =.84	Rel =.81
Medium Probability HTCs	Rel =.79 / Rel_{adj} =.78	Rel =.80
High Probability HTCs	Rel =.77 / Rel_{adj} =.76	Rel =.73
Low Reward HTCs	Rel =.82 / Rel_{adj} =.83	Rel =.80
Medium Reward HTCs	Rel =.82 / Rel_{adj} =.81	Rel =.78
High Reward HTCs	Rel =.82 / Rel_{adj} =.82	Rel =.79
New EEfRT task		
Clicks	Rel =.96 / Rel_{adj} =.92	-
Low Probability Clicks	Rel =.91 / Rel_{adj} =.87	-
Medium Probability Clicks	Rel =.96 / Rel_{adj} =.91	-
High Probability Clicks	Rel =.97 / Rel_{adj} =.93	-
Reward 1 Cent Clicks	Rel =.88 / Rel_{adj} =.84	-
Reward 2 Cent Clicks	Rel =.90 / Rel_{adj} =.82	-
Reward 3 Cent Clicks	Rel =.95 / Rel_{adj} =.89	-
Reward 4 Cent Clicks	Rel =.93 / Rel_{adj} =.84	-
Reward 5 Cent Clicks	Rel =.95 / Rel_{adj} =.88	-

Note. Depicted are internal consistencies of questionnaire measures and split-half reliabilities of task measures. α = Cronbach's Alpha, Rel = split-half reliability calculated by Spearman-Brown correcting the split-half correlation of task measures, adj = adjusted for motor abilities: variables were predicted by maximum clicks in motoric trials and residuals were used to calculate reliability, EEfRT = Effort Expenditure for Reward Task, HTC = Hard Task Choices.

3.2 Experiment 1

3.2.1 Original EEfRT - Validity of Basic Task Variables

Participants on average chose the hard task in 53.41% of all trials (*SD* = 18.50%; Range = 2.90 – 100%). We conducted a GEE model to test validity of the basic task variables within the original EEfRT in Study 1 (see Table 3). The GEE model examined the main effects of task-dependent variables (reward magnitude, probability of reward attainment, and trial number) as well as one variable unique to our study (MaxMot) on the percentage of hard-task-choices. In line with previous studies, a significant positive main effect was found for reward magnitude and probability of reward attainment and a significant negative main effect was found for trial number, indicating that all three factors were predictors of percentage of hard-task choices (all *p*s < .001). Furthermore, the interaction of reward and probability (often referred to as "expected value") did also reach significance, indicating that higher probability did predict a higher percentage of hard-task-choices with increasing reward magnitude (see Figure 3). The factor MaxMot reached also significance ($\beta = 0.02$, $\chi^2(1) = 9.06$, $p = .003$), indicating that participants with greater motoric ability as measured within the motoric trials did chose the hard task more often within the original EEfRT.

Table 3. GEE Models for basic predictors of percentage of hard-task choices within the original EEfRT in Study 1 and 2 and of mean number of clicks within the modified EEfRT in Study 1.

Effect	***β***	***se***	χ^2	***p***
Study 1 – Original EEfRT				
Reward Magnitude	0.87	0.09	99.44	**<.001**
Probability 50%[a]	1.70	0.13	162.74	**<.001**
Probability 88%[a]	3.40	0.26	167.20	**<.001**
Probability 50%[a] × Reward Magnitude	0.51	0.11	23.81	**<.001**
Probability 88%[a] × Reward Magnitude	1.08	0.20	28.43	**<.001**
Trial	-0.75	0.01	36.47	**<.001**
MaxMot	0.02	0.01	9.06	**.003**
Study 1 – Modified EEfRT				
Reward Magnitude	4.91	0.46	111.80	**<.001**
Probability 50%[a]	12.47	1.07	135.45	**<.001**
Probability 88%[a]	17.80	1.53	135.98	**<.001**
Probability 50%[a] × Reward Magnitude	-1.33	0.38	12.19	**<.001**
Probability 88%[a] × Reward Magnitude	-1.83	0.43	18.51	**<.001**
Trial	-5.96	0.90	43.58	**<.001**
Block	-2.22	0.57	14.95	**<.001**
MaxMot	0.61	0.05	149.48	**<.001**
Study 2 – Original EEfRT				
Reward Magnitude	0.73	0.04	264.95	**<.001**
Probability 50%[a]	1.68	0.07	561.36	**<.001**
Probability 88%[a]	3.06	0.13	589.89	**<.001**
Probability 50%[a] × Reward Magnitude	0.39	0.05	53.65	**<.001**
Probability 88%[a] × Reward Magnitude	0.70	0.09	64.68	**<.001**
Trial	-0.70	0.07	92.47	**<.001**

Note. All models included probability (categorical), reward magnitude and trial number as within-subjects variables; χ^2 = Wald chi-square; β = regression coefficient; significant effects in **bold.**

[a]Reference category: 12% probability

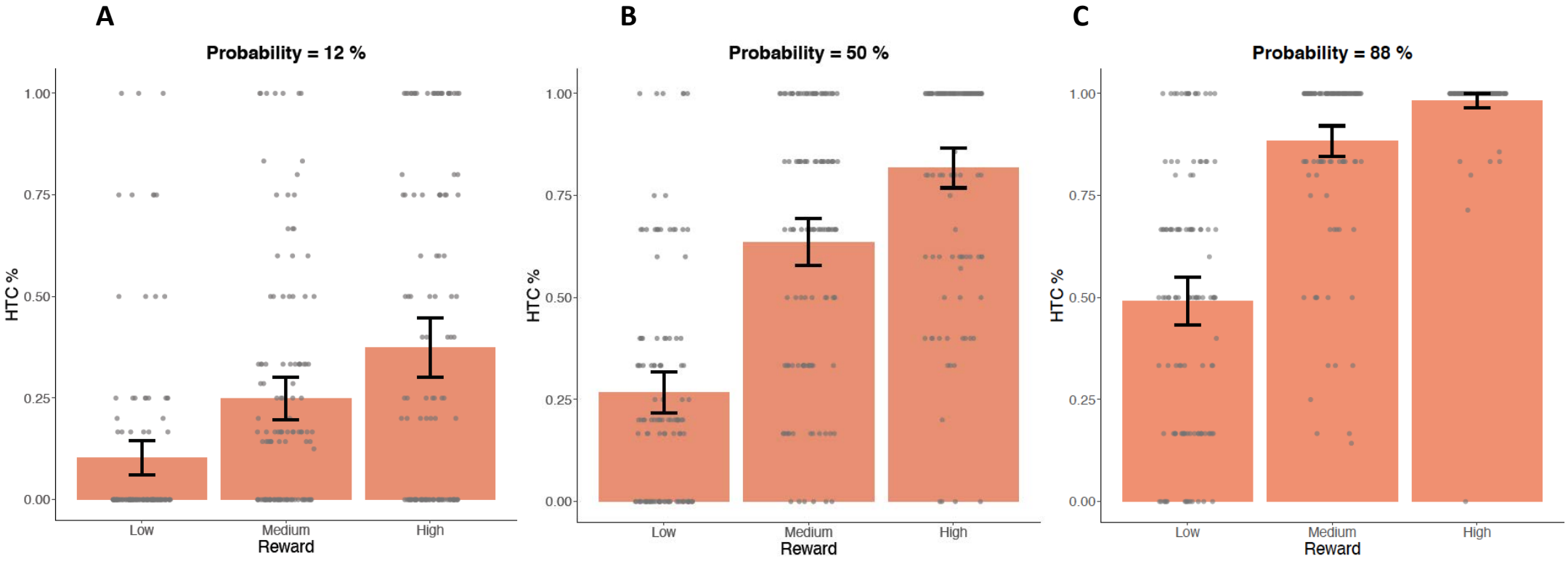

*Figure 3. P*ercentage of hard-task-choices (HTC), comparing trials with low probability of reward attainment (left; A), medium probability of reward attainment (middle; B) and high probability of reward attainment (right, C) within the original EEfRT in Study 1. For each probability category, all three categories of reward magnitude (low / medium / high) are displayed. Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

3.2.2 Modified EEfRT - Validity of Basic Task Variables

Participants on average exerted 117,71 number of clicks in each trial (*SD* = 16.03; Range = 77.17 – 156.43). In accordance with our analysis of the original EEfRT (see 3.1.1), we computed a GEE model to test validity of the basic task variables within the modified EEfRT in Study 1 (see Table 3). The GEE Model examined main effects of task-dependent variables (reward magnitude, probability of reward attainment, and trial number) as well as one variable unique to our study (MaxMot) capturing the mean number of clicks. In line with previous studies, significant positive main effects were found for reward magnitude and probability of reward attainment and a significant negative main effect was found for trial number, indicating all three factors were predictors of the mean number of clicks (all *p*s < .001). Furthermore, the interaction of reward and probability (often referred to as "expected value") also reached significance ($p < 0.001$), indicating that higher probability predicted a stronger increase of mean number of clicks for smaller reward magnitudes (see Figure 4). The factor MaxMot also reached significance ($\beta = 0.61$, $\chi^2(1) = 149.48$, $p < .001$), indicating that participants with greater motoric ability as measured within the motoric trials exerted more clicks within the modified EEfRT.

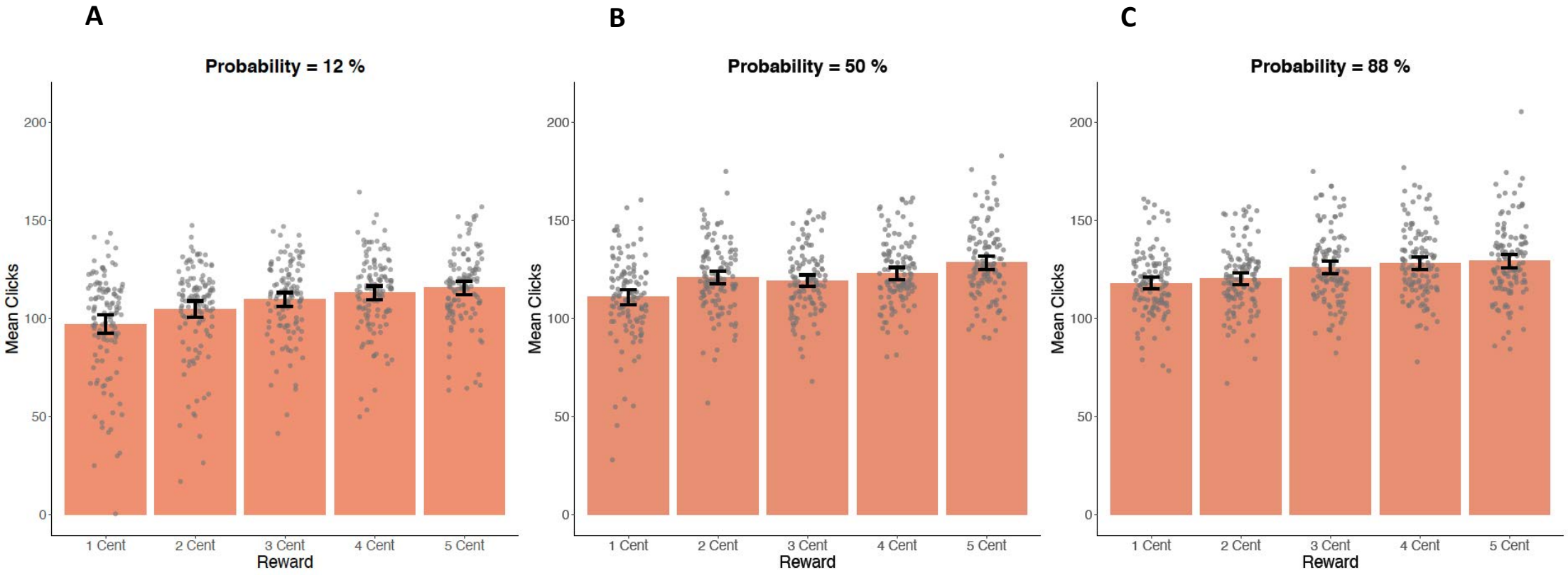

Figure 4. Mean number of clicks, comparing trials with low probability of reward attainment (left; **A**), medium probability of reward attainment (middle; **B**) and high probability of reward attainment (right; **C)** within the modified EEfRT in Study 1. For each probability category, all 5 different reward magnitudes (ranging from 1 Cent (most left) to 5 Cent (most right) are displayed. Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

3.3 Experiment 2

3.3.1 Original EEfRT - Validity of Basic Task Variables

Participants on average chose the hard task in 53.31% of all trials (*SD* = 19.21%; Range = 0 – 100%). We computed a GEE model to test the validity of basic task variables within the original EEfRT in Study 2 (see Table 3). The GEE Model examined main effects of task-dependent variables (reward magnitude, probability of reward attainment, and trial number) on the percentage of hard-task-choices. In line with previous studies and Study 1, significant positive main effects were found for reward magnitude and probability of reward attainment, and a significant negative main effect was found for trial number, indicating that all factors were predictors of the percentage of hard-task choices (all *p*s < .001). Furthermore, the interaction of reward and probability (often referred to as "expected value") did reach significance ($p < .001$), indicating that higher probability did predict a higher percentage of hard-task-choices with increasing reward magnitude (see Figure 5).

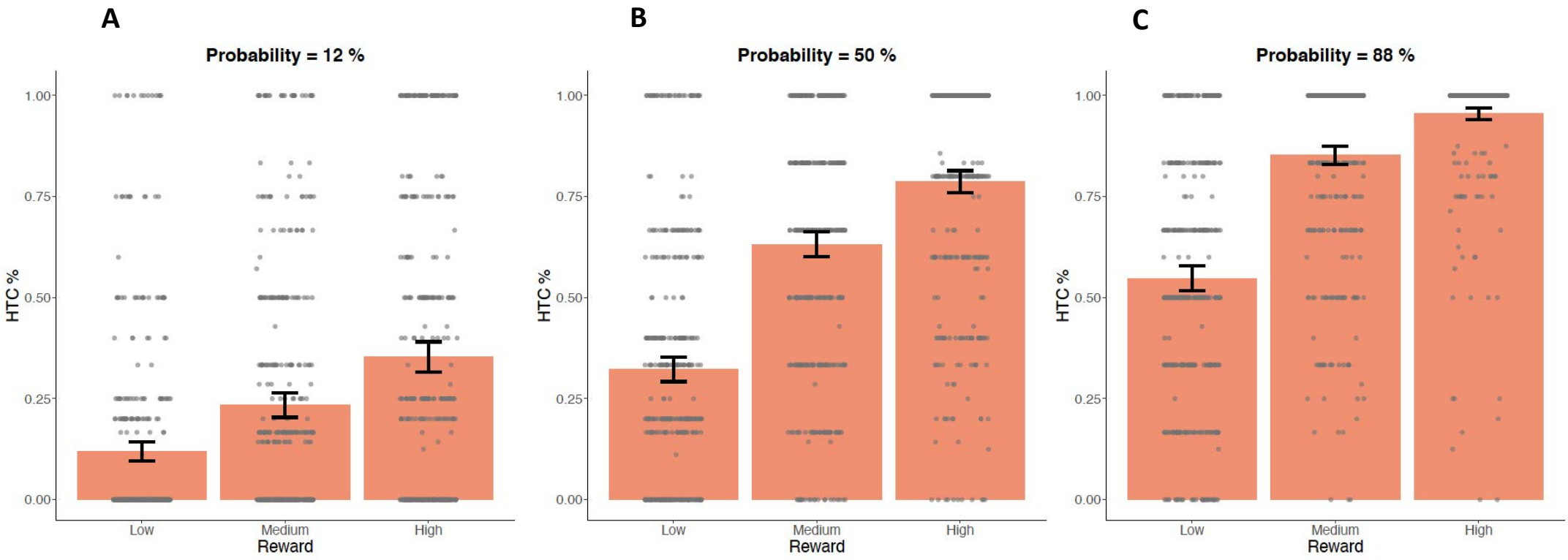

Figure 5. Percentage of hard task choices (HTC), comparing trials with low probability of reward attainment (left; **A**), medium probability of reward attainment (middle; **B**) and high probability of reward attainment (right; **C**) within the original EEfRT in Study 2. For each probability category all three reward magnitude categories (low / medium / high) are displayed. Data points are added as dots for individual scores. Error bars depict a 95% confidence interval (CI) of the mean.

3.4 Personality correlations

To further validate the original and the modified EEfRT, we exploratorily correlated the percentage of hard-task-choices within the original EEfRT (Study 1 and Study 2) and the mean number of clicks within the modified EEfRT (Study 1) with personality traits as well as the mean number of pumps in the BART (Study 1). We compared all trial categories as well as difference scores (see Table 4 and 5). Difference scores indicate individual differences in the degree to which participants' hard task choices or clicks are influenced by the probability of reward attainment and the reward magnitude, respectively. Surprisingly, trait BAS did not correlate significantly with the percentage of hard-task-choices in trials with low probability of reward attainment within the original EEfRT in both studies, nor with the mean number of clicks within the modified EEfRT in trials with low probability of reward attainment (see Figure 6). However, in the original EEfRT in Study 1, trait BAS correlated negatively with the difference score between trials with high probability of reward attainment and low probability of reward attainment. Conversely, trait BIS correlated positively with both difference scores (high probability minus low / medium probability trials). Trait anticipatory pleasure correlated positively with number of hard task choices within trials with low probability of reward attainment, as well as negatively with the difference score between trials high probability of reward attainment and trials with low probability of reward attainment. Out of these correlations, only two were similar when comparing trials with different reward magnitudes. Trait BIS correlated negatively with the difference score between trials with high reward magnitude and low reward magnitude. Trait anticipatory pleasure correlated positively with number of hard-task-choices within trials with low reward magnitude. Importantly, none of these correlations could be replicated in Study 2. Note, however, that we did not administer the TEPS questionnaire and the BART in Study 2. The analyses for the modified EEfRT, which was administrated in Study 1 only, revealed a different pattern of results compared to the original EEfRT. Trait anticipatory pleasure correlated negatively with the difference score

between trials with high probability of reward attainment and trials with medium probability of reward attainment. Moreover, risk-taking behavior as measured via the BART correlated positively with the mean number of clicks in trials with medium and high probabilities of reward attainment. These findings were similar when examining reward magnitudes. Risk-taking behavior (BART) correlated positively with the mean number of clicks in trials with medium and high reward magnitudes.

Table 4. Correlations between the original EEfRT (percentage of hard-task -choices), the modified EEfRT (mean number of clicks) and trait variables (Study 1 and 2).

Trait variable	**Reward Probability**				
Original EEfRT (Study 1)	**12%**	**50%**	**88%**	**88-12%**	**88-50%**
BAS	.148	.018	-.073	**-.181***	-.074
BIS	-.114	-.105	.165	**.203***	**.238****
TEPS – anticipatory pleasure	**.291****	.164	.047	**-.243****	-.143
TEPS – consummatory pleasure	.154	-.007	-.010	-.149	.000
UPPS-Urgency	-.095	-.066	-.065	.050	.023
UPPS-Premeditation	.058	.016	-.131	-.131	-.116
UPPS-Perseverance	.029	-.039	-.006	-.031	.037
UPPS-Sensation Seeking	.115	.086	.095	-.051	-.023
BART	.021	.123	.148	.068	-.023
Original EEfRT (Study 2)					
BAS	-.024	-.022	.059	.060	.079
BIS	-.066	-.027	.004	.063	.036
UPPS-Urgency	.025	.065	**.105***	.044	.015
UPPS-Premeditation	-.035	-.015	.050	.064	.061
UPPS-Perseverance	.006	.023	-.017	-.017	-.043
UPPS-Sensation Seeking	-.018	.051	-.026	.000	-.084
Modified EEfRT (Study 1)					
BAS	.015	.045	-.007	-.024	-.123
BIS	.064	.108	.075	.001	-.071
TEPS – anticipatory pleasure	.075	.037	-.055	-.145	**-.222***
TEPS – consummatory pleasure	.049	.080	.048	-.010	-.072
UPPS-Urgency	.016	-.040	-.081	-.101	-.103
UPPS-Premeditation	-.032	-.036	-.080	-.044	-.111
UPPS-Perseverance	-.064	-.123	-.119	-.046	.000
UPPS-Sensation Seeking	.017	.041	.055	.036	.037
BART	.126	**.230***	**.249****	.106	.067

Note. EEfRT = Effort Expenditure for Rewards Task; BAS = Behavioral Activation System; BIS = Behavioral Inhibition System scale; TEPS: Temporal Experience of Pleasure Scale; UPPS = Urgency Premeditation Perseverance and Sensation Seeking Impulsive Behavior Scale; BART = Balloon Analogue Risk Task; significant effects in **bold**. * $p < .05$; ** $p < .01$

Table 5. Correlations between the original EEfRT (percentage of hard-task -choices), the modified EEfRT (mean number of clicks) and trait variables (Study 1 and 2)

Trait variable	**Reward Magnitude**				
Original EEfRT (Study 1)	**low**	**medium**	**high**	**high-low**	**medium-low**
BAS	.113	.055	-.055	-.159	-.147
BIS	.066	-.066	-.135	**-.180***	-.086
TEPS – anticipatory pleasure	**.235***	.178	.160	-.097	-.034
TEPS – consummatory pleasure	.061	.083	.023	-.041	-.083
UPPS-Urgency	-.131	-.072	-.021	.112	.070
UPPS-Premeditation	-.067	-.003	.069	.125	.094
UPPS-Perseverance	-.039	-.042	.090	.115	.175
UPPS-Sensation Seeking	.117	.107	.074	-.053	-.049
BART	.050	.115	.117	.050	-.004
Original EEfRT (Study 2)					
BAS	-.026	.006	.020	.046	.058
BIS	-.029	-.035	-.051	-.013	-.018
UPPS-Urgency	.036	.079	.092	.043	.010
UPPS-Premeditation	.009	-.009	-.025	-.032	-.007
UPPS-Perseverance	.017	.016	-.010	-.027	-.048
UPPS-Sensation Seeking	-.007	.026	-.010	-.001	-.091
Modified EEfRT (Study 1)					
BAS	.046	.006	-.006	-.089	-.044
BIS	.101	.082	.069	-.060	-.037
TEPS – anticipatory pleasure	.080	-.016	-.020	-.168	-.014
TEPS – consummatory pleasure	.069	.042	.062	-.018	.072
UPPS-Urgency	-.017	-.031	-.054	-.059	-.082
UPPS-Premeditation	-.060	-.051	-.041	.037	.032
UPPS-Perseverance	-.150	-.095	-.060	.159	.115
UPPS-Sensation Seeking	.024	.035	.055	.048	.071
BART	.154	**.224***	**.253****	.145	.120

Note. EEfRT = Effort Expenditure for Rewards Task; BAS = Behavioral Activation System; BIS = Behavioral Inhibition System scale; TEPS: Temporal Experience of Pleasure Scale; UPPS = Urgency Premeditation Perseverance and Sensation Seeking Impulsive Behavior Scale; BART = Balloon Analogue Risk Task; significant effects in **bold**. * $p < .05$; ** $p < .01$

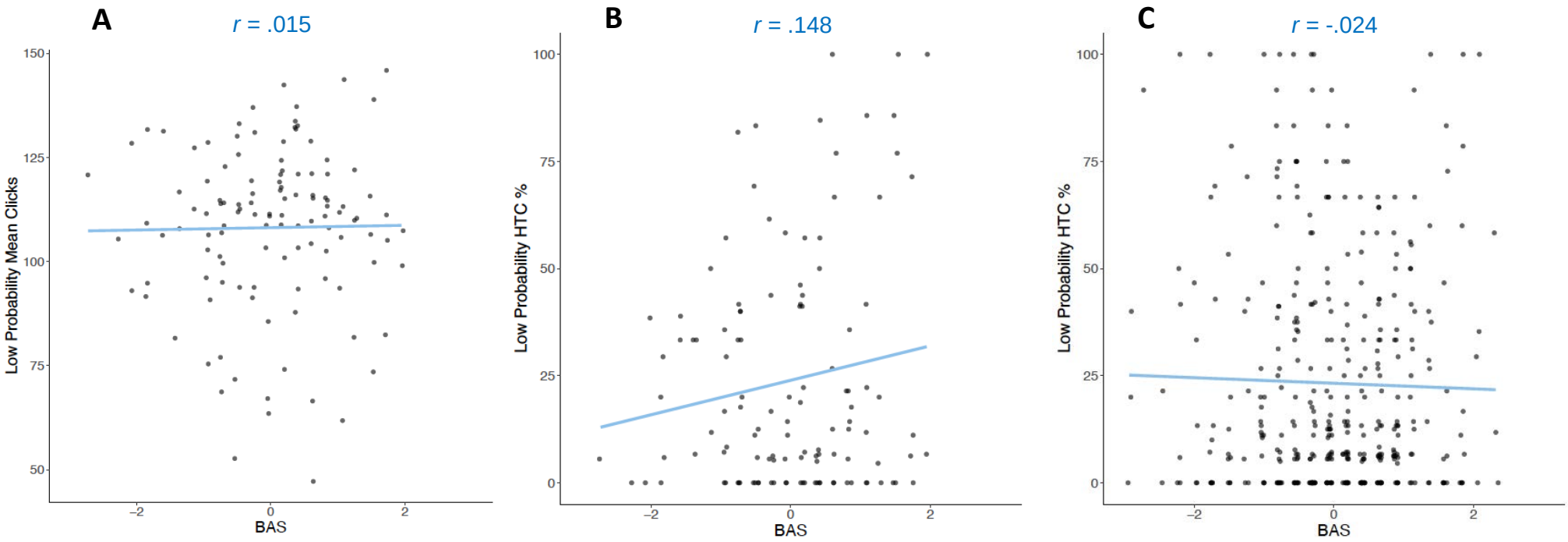

Figure 6. Pearson correlations between trait BAS scores (z-standardized) and mean number of clicks within trials with low probability of reward attainment in the modified EEfRT (**A:** Study 1) and percentage of hard task choices within trials with low probability of reward attainment in the original EEfRT (**B**: Study 1; **C:** Study 2).

3.5 Secondary Analyses

As Study 1 is one of the first studies to test two versions of the EEfRT within one experimental design, we further evaluated the validity of both tasks by exploratorily correlating the main dependent variables of both task versions within all three different probability of reward attainment categories (low: 12% / medium: 50% / high: 88%; see Figure 7) and all three different reward magnitude categories (low / medium / high). The correlations between the dependent variables of both tasks was significant for all probabilities of reward attainment. Furthermore, the correlation between the dependent variables of both tasks was significant for trials with medium and high reward magnitudes. These results indicate an overall linkage (albeit only moderate in size) between performance on both task versions, as subjects who choose the hard task more often on the original EEfRT also exert more clicks within the modified EEfRT.

Additionally, we asked participants to self-evaluate aspects that might have influenced their effort allocation individually for both task versions and asked them about their motivation to win money throughout the whole study. We then exploratorily correlated theses evaluations to their actual effort allocation in Study 1 comparing different trial categories and difference scores (see Table 6 and 7).

In line with our GEE analysis, which indicated probability of reward attainment and reward magnitude to be strongly connected to actual task performance, participants` self-evaluated importance of these two factors for their task performance correlated strongly with various trial categories in both task versions of the EEfRT. A comparable pattern was found for the modified EEfRT (see Table 6 and 7). The self-evaluated importance of reward magnitude was less strongly associated with performance in both task versions, although some moderately sized correlations emerged. When correlating participants` self-evaluated importance of fatigue for their task performance throughout the task, only two significant effects were observed. The percentage of hard task choices within the original EEfRT correlated

negatively within trials with medium reward magnitude and with the difference score between trials with high probability of reward attainment and medium probability of reward attainment. When correlating participants` self-evaluated importance of resting their fingers for their performance throughout the modified EEfRT, this evaluation correlated significantly with the difference score between trials with high probability of reward attainment, indicating that participants who tried to rest their fingers more strongly, did so more often on trials with medium probability of reward attainment. A comparable result pattern was found for the original EEfRT. The strategy to rest their fingers was especially often used for trials with low and medium reward magnitudes, which is also reflected by the difference score between trials with high reward magnitude and medium reward magnitude. Finally, when correlating participants` motivation to win money throughout the whole study, the mean number of clicks within the modified EEfRT correlated significantly within trials with all probability levels, as well as with trials with medium and high reward magnitudes, indicating that participants with high motivation to win money performed more clicks in almost all trial categories (see Table 6 and 7). In contrast to the modified EEfRT, the percentage of hard-task-choices within the original EEfRT did not correlate with participants` motivation to win money in any trial category.

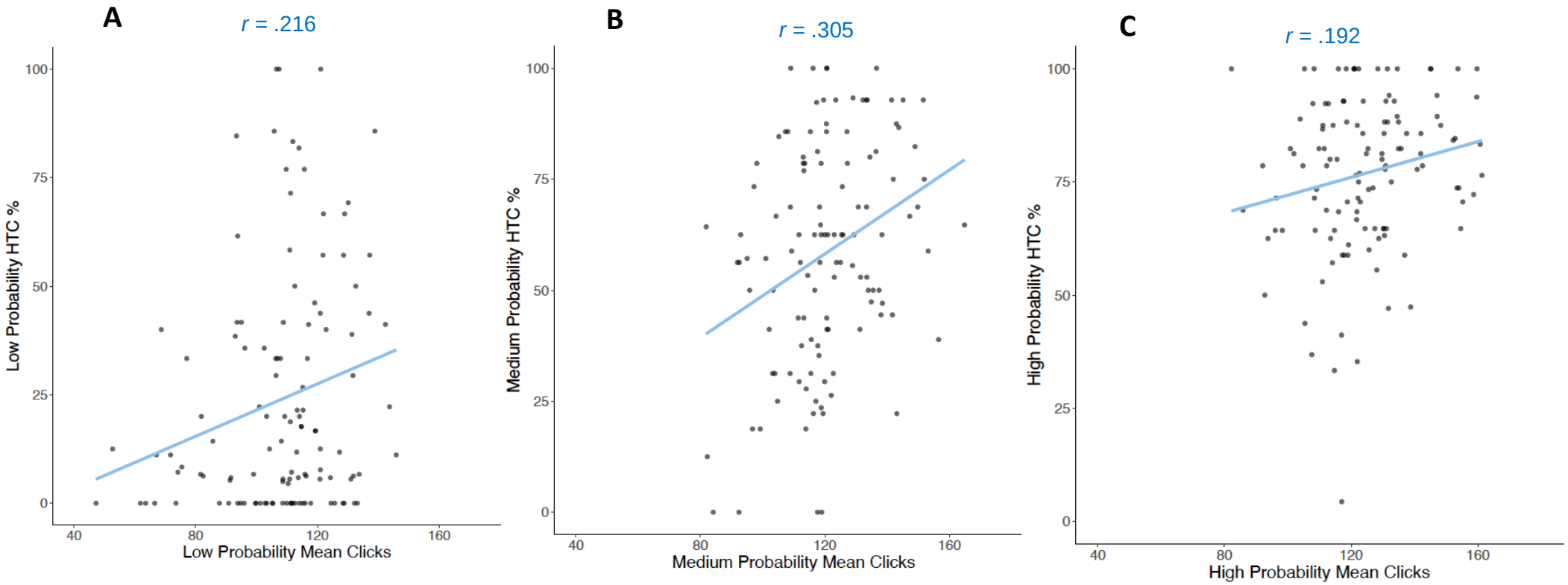

Figure 7. Pearson correlations between the percentage of hard-task-choices (HTC %) within the original EEfRT and the mean number of clicks within the modified EEfRT for **A:** trials with low probability of reward attainment (= 12%), **B:** medium probability of reward attainment (=50%) and **C:** high probability of reward attainment (=88%) in Study 1.

Table 6. Zero-order correlations between the original EEfRT (percentage of hard-task - choices), the modified EEfRT (mean number of clicks) and follow-up questions concerning task strategy and motivation in Study 1.

Strategy and motivation	**Reward Probability**				
Original EEfRT	**12%**	**50%**	**88%**	**88-12%**	**88-50%**
Reward	.118	**.219***	.041	-.086	**-.207***
Probability	**-.513****	**-.232***	.128	**.552****	**.348****
Fatigue	-.092	-.082	-.078	.040	.030
Resting fingers	-.199	-.156	-.093	.130	.100
Motivation to win money	-.085	-.002	.069	.120	.054
Modified EEfRT					
Reward	.140	.172	.155	-.007	-.026
Probability	**-.200***	.017	.144	**.382****	**.312****
Fatigue	-.122	-.055	.030	.175	**.204***
Resting fingers	-.171	-.140	-.053	.149	**.201***
Motivation to win money	**.192***	**.231***	**.238****	.015	.035

Notes. EEfRT = Effort Expenditure for Rewards Task. The following five-point Likert-scales ranging from "not at all" (1) to "a lot" (5) were administered separately for each task: Reward: "How much did the reward magnitudes influence you on the task?"; Probability: "How much did the probabilities of reward attainment influence you on the task?"; Fatigue: "How much did Fatigue influence you on the task?"; Resting Fingers: "How much did attempts to rest your fingers influence you on the task?". The last question (same response format) was asked only once (i.e., not separately for each task): Money: "How motivated were you to win money throughout the whole study?". **bold**. * $p < .05$ ** $p < .01$

Table 7. Zero-order correlations between the original EEfRT (percentage of hard-task - choices), the modified EEfRT (mean number of clicks) and follow-up questions concerning task strategy and motivation in Study 1.

Strategy and motivation	**Reward Magnitude**				
Original EEfRT	**low**	**medium**	**high**	**high-low**	**high-medium**
Reward	.126	**.190***	**.227***	.068	.038
Probability	**-.244****	**-.261****	**-.258****	.022	.019
Fatigue	-.097	**-.220***	-.148	-.030	.106
Resting fingers	**-.192***	**-.279****	-.152	.061	**.183***
Motivation to win money	-.002	-.024	-.052	-.043	-.035
Modified EEfRT					
Reward	.116	**.190***	**.196***	.118	.039
Probability	**-.123***	.020	.059	**.306****	.139
Fatigue	-.100	-.022	-.023	.134	-.006
Resting fingers	-.163	-.124	-.096	.123	.087
Motivation to win money	.177	**.253****	**.271****	.136	.088

Notes. EEfRT = Effort Expenditure for Rewards Task. The following five-point Likert-scales ranging from "not at all" (1) to "a lot" (5) were administered separately for each task: Reward: "How much did the reward magnitudes influence you on the task?"; Probability: "How much did the probabilities of reward attainment influence you on the task?"; Fatigue: "How much did Fatigue influence you on the task?"; Resting Fingers: "How much did attempts to rest your fingers influence you on the task?". The last question (same response format) was asked only once (i.e., not separately for each task): Money: "How motivated were you to win money throughout the whole study?". **bold**. * $p < .05$ ** $p < .01$

4.Discussion

In the present study, we aimed to (1) validate the original EEfRT (Treadway et al., 2009) and a modified version of the EEfRT (Ohmann, Kuper & Wacker, 2020) as measures of approach motivation by directly comparing both versions within one experimental design (Study 1) and to replicate the reliability and validity of the original EEfRT within a large sample (Study 2). We further aimed to (2) test the correlations between self-reported personality traits and behavioral measurements for different trial categories and difference scores, as well as between self-reported strategy usage, motivation and task performance in an exploratory fashion. We will now discuss the implication of the current findings.

4.1 Reliability and Validity of the original and modified version of the EEfRT

Supporting the results of previous studies (Reddy et al., 2015; Horan et al., 2015; Ohmann et al., 2020) both the original EEfRT and the modified EEfRT showed overall good reliability, indicating that both versions are producing reliable results. In terms of validity, our results are mixed. The validity of both tasks got further support from the GEE models in both studies as the basic task variables are in line with previous studies replicating the typical pattern of effects of reward magnitude, probability of reward attainment and trial number on the mean number of clicks (modified EEfRT) and the percentage of hard-task-choices (original EEfRT). It can be concluded that both studies replicated the basic validity of the EEfRT. Furthermore, we were able to show that both versions of the EEfRT did correlate significantly within all three probability of reward attainment categories as well as in trials with medium and high reward magnitudes in Study 1, indicating a meaningful conceptual linkage between both tasks.

Regarding the relationship between the self-ascribed personality traits and behavioral task measures, our correlations in both studies showed only weak support for such a link. Only in Study 1, trait BAS and trait anticipatory pleasure correlated significantly with the percentage of hard task choices within the original EEfRT and with the mean number of

clicks within the modified EEfRT. However, in contrast to our expectations the correlating task parameters were not the same as in previous studies (Geaney et al., 2015; Ohmann et al., 2020). Furthermore, trait BIS correlated negatively with task performance in the original EEfRT in Study 1, indicating that participants with higher trait BIS did choose the hard task less frequently in trials with lower probability of reward attainment as compared to trials with higher probability of reward attainment, as well as less often in trials with low reward magnitudes as compared to trials with high reward magnitudes. However, as we analyzed the correlations of trait BAS and trait BIS for the original EEfRT within a larger sample in Study 2, none of these correlations replicated. These findings raise further questions about the existence of such links, supporting studies not replicating them (Horan et al., 2015; Anand et al., 2016; Kaack et al., 2020). In particular, some correlations in previous work as well as Study 1 may have been overestimated due to random sampling error. Significant correlations may be at least partly attributable to the large number of possible correlations between task parameters and self-report measures. Analyzing the correlations between performance on the BART and both task versions of the EEfRT in Study 1 revealed unexpected correlations between the mean number of clicks within the modified EEfRT and the mean number of pumps within the BART, indicating that risk-taking behavior might have impacted task performance as well, although this requires further replication.

Taken together, the results of our data show a very mixed pattern regarding the validity of the EEfRT. Therefore, our results support a multiply determined view on behavioral measurements (Gignac & Szodorai, 2016). Putting our results into a broader context, they are well in line with other studies that indicate that effort allocation within the EEfRT can be manipulated by a wide range of factors, ranging from mood inductions (Geaney et al., 2015) and neurophysiological manipulations (Wardle et al., 2012; Ohmann et al., 2018; Ohmann et al., 2020) to the influence of reduced motivation (Treadway et al., 2009), or the intake of caffeine (Wardle et al., 2012). So how does a person decide whether to

increase her effort to potentially gain a greater monetary reward within the EEfRT? Our mixed pattern of results shows that there is a no simple answer to this question. Especially the impact of reward attributes hints at a complex pattern behind participants decisions and at the importance of individual reward evaluation. Reward-based decision making is not a uniform process, it can rather be described as a set of distinct cognitive processes, which together direct the evaluation of a reward and thus form a person`s decisions within a concrete situation. According to Orsini et al. (2019) reward-based (or "value-based") decision-making comprises of three phases: 1. Decision representation (different options are identified, as are the costs and benefits associated with each option) and option valuation (each option is also assessed in terms of its subjective value in the moment of the decision), 2. action selection and 3. outcome evaluation (the value of the outcome of a choice is compared with the expected value of that outcome). It is reasonable to assume that the evaluation of potential benefits and costs can differ greatly between participants and goes beyond personality traits. A potentially important factor is the type of reward and how much a person values this reward. Real-life reward types include i.e. social (Forbes & Dahl, 2012), physical (Chapman et al., 1976; Zhang et al., 2016), and recreational (Johnson et al., 2012; Ryba & Hopko, 2012) rewards and their valuation has been successfully differentiated via self-reports (Khazanov et al., 2020). As stated above, Lopez-Gamundi & Wardle (2018) were able to show that participants did choose the hard task more often within a modified version of the EEfRT using cognitive tasks (C-EEfRT), although participants described the modified version as more difficult. The cognitive challenge of the modified version might have been rewarding in itself (although the monetary reward magnitude was unchanged). These results indicate that "costs" and "benefits" within a task can also be related to properties of the task itself. To reach a better understanding of the self-evaluated aspects which might have influenced participants decisions, we asked them a series of questions about their strategies and motivation at the end of Study 1. We were able to show that effort allocation on both task version was impacted by

the self-evaluated importance of probability of reward attainment and by the reward magnitude, indicating that participants are well aware of the factors that impact their behavior. Surprisingly, participants self-evaluated motivation to win money throughout the whole study correlated positively only with the mean number of clicks within the modified EEfRT, in all three categories of probability of reward attainment as well as in trials with medium and high reward magnitudes. The percentage of hard-task-choices within the original motivation was not correlated to this self-evaluated monetary motivation. These results indicate that the individual evaluation of "costs" and "benefits" differs between both versions of the EEfRT, and hints at a potentially better validity of the modified EEfRT.

On the same note, one should also consider the nature of the questionnaires which assess personality traits, like trait BAS (Carver & White, 1994; Strobel et al., 2001), trait anticipatory pleasure (Gard et al., 2006) or trait impulsivity (Whiteside & Lynam, 2001; Schmidt et al., 2008): These questionnaires comprise of questions about various different situations, most of them complex real-life situations. Linking those accumulated scales to behavior in one artificial experimental situation might be rather difficult. This does not implicate that the EEfRT is not able to measure approach motivation. But it indicates that behavior in one situation (affected by multiple factors) could be too limited to assess global personality traits.

4.2 Limitations and future directions

Although we analyzed two rather large samples to test the reliability and validity of the original and the modified version of the EEfRT and our study is one of the first to directly compare two versions of the EEfRT within one experimental design, there are still some limitations to our study. First, although we tried to stick as close to the original version of the EEfRT as possible (Treadway et al., 2009), there is still a small adaption, which might have impacted participants` behavior. The adaption is based on a study by Hughes et al. (2015), who decided to pay participants a percentage of the virtually won money instead of paying

participants the money which they have won on two random trials (Treadway et al., 2009). We followed this adaption, as we expected the non-random payment to increase participants` overall approach motivation. However, we did not expect this adaption to change the response pattern in any significant way, which is also supported by our results replicating the basic predictors (i.e. reward attributes). Nonetheless, as we stated in the introduction, many smaller and larger adaptions of the EEfRT have been installed in various studies, ranging from reduced complexity by fixing the monetary rewards (Yang et al., 2014), or by removing trials with low probability of reward attainment (Damiano et al., 2012) to the addition of "loose" – trials (Byrne & Ghaiumy Anaraky, 2019), or the addition of a social component (Gilman et al., 2015). Thus, we cannot rule out that even our small modification might have caused a significant change in behavior within the original EEfRT. Furthermore, although both task versions used in Study 1 correlated significantly suggesting some conceptual overlap, the correlations ranging from r = .160 to .305 also indicate that the variable(s) captured by the two tasks also differ substantially. Figure 7 indicates that this might partly be a result of floor-, and ceiling-effects regarding the effort allocation within original EEfRT (especially in trials with low and high probability of reward attainment). Future studies should therefore always consider that any change made to the original EEfRT e.g., to make the task fit to the experimental setting could lead to substantial changes in behavior and should therefore carefully compare any new version of the EEfRT to the original version. Second, although we were able to test the original EEfRT within a large sample in Study 2, the comparison of both studies is limited. As stated in the methods section, the original EEfRT was part of a larger genetic study in Study 2 and task administration took place approximately 4 hours after start of the testing session. It is reasonable to assume that completing the task after 4 hours of testing might be influenced by participants' fatigue or boredom. Study 1 on the other hand lasted for only one hour at our lab, which might have led to less fatigue or boredom. Third, both samples comprised mainly of young healthy students and both samples were not

balanced in terms of age or gender. We would like to state that the results of our research cannot be generalized to broader populations. Although the original EEfRT has demonstrated to be a sensitive tool for detecting reduced approach motivation within various clinical samples (Fervaha et al., 2013; Barch et al., 2014; McCarthy et al., 2016; Chang et al., 2019; Treadway et al., 2012; Yang et al., 2014; Damiano et al., 2012), we cannot rule out that the results we found regarding the reliability and validity of the EEfRT could show a different pattern for other populations e.g. within clinical samples. Fourth, as we discussed above, the rather mixed results regarding the validity of the original and the modified EEfRT might be a result of correlating scales from self-reports summarizing a large set of real-life situations and behavioral measurements within one computational task. The EEfRT comprises investing physical effort for monetary rewards. Other forms of effort as well as other forms of rewards should be introduced and tested. Furthermore, we suggest assessing approach motivation should not be limited on one specific "cost" and one specific "benefit". Authors should rather use a range of tasks or a range of variations of the EEfRT and calculate scales comparable to questionnaires assessing personality traits. The EEfRT offers a solid foundation to probe other forms of "costs" (i.e. the C-EEfRT which uses cognitive tasks; Lopez-Gamundi & Wardle, 2018) and a variety of different "benefits" (i.e. food potions; Racine et al., 2018).

4.3 Conclusion

Taken together, our findings provide additional support for the reliability of the original and the modified version of the EEfRT. Furthermore, the correlations between both task versions provide evidence for the conceptual overlap of both task versions. The results regarding the validity of the tasks are mixed. While the basic predictors of both task versions replicated well in both studies and are also supported by participants' self-evaluated importance of these factors, we were not able to replicate previous findings linking trait BAS and trait anticipatory pleasure to effort allocation within both versions of the EEfRT as only some performance

parameters in Study 1 correlated to personality traits. Study 2 with a larger sample did not reveal any correlation between trait BAS and trait BIS for the original EEfRT. Furthermore, self-evaluated motivation hints at an advantage of the modified EEfRT regarding its validity. Our results indicate a complex interaction of personality traits, task properties, reward attributes and study design. Furthermore, they highlight the importance of analyzing the reliability and validity of the EEfRT and any modification applied to the task.

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