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Early Approach and Avoidance Tendencies can be Goal-Directed: Support from a Transcranial Magnetic Stimulation Study

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Abstract

Dual-process models with a default-interventionist architecture explain early emotional action tendencies by a stimulus-driven process, and they allow goal-directed processes to intervene only in a later stage. An alternative dual-process model with a parallel-competitive architecture developed by Moors, Boddez, and De Houwer (*Emotion Review*, 9(4), 310-318, 2017), in contrast, explains early emotional action tendencies by a goal-directed process. This model proposes that stimulus-driven and goal-directed processes often operate in parallel and compete with each other, and that if they do compete, the goal-directed process often wins the competition. To examine these predictions, we set up a goal-directed process in an experimental group by rewarding participants for avoiding positive stimuli and for approaching negative stimuli and punishing them for the opposite behavior. We expected this process to compete with a potentially preexisting stimulus-driven process in which positive stimuli are associated with approach and negative stimuli with avoidance. We compared the elicited action tendencies of participants in this group with a control group in which only the stimulus-driven process could operate. Early approach and avoidance tendencies were assessed via motor evoked potentials (MEP) measured in the finger muscles previously trained to approach or to avoid stimuli after single-pulse transcranial magnetic stimulation (TMS) delivered at 400 ms. Results confirmed that positive/negative stimuli led to stronger avoidance/approach tendencies in the experimental group but not to approach/avoidance tendencies in the control group. This suggests that goal-directed processes are indeed able to determine relatively early emotional action tendencies, but it does not show that goal-directed process can defeat stimulus-driven processes.

Keywords Stimulus-driven · Goal-directed · Emotional behavior · Parallel-competitive · Default-interventionist · Transcranial magnetic stimulation

Traditional accounts of emotional behavior are dual-process models that explain this behavior by the interplay of stimulus-driven and goal-directed processes. A stimulus-driven process is held responsible for the initial emotional action tendency and a goal-directed process for the refinement or correction of this initial action tendency (Moors, Boddez, & De Houwer, 2017). This view can, for instance, explain how the smell of a delicious cake can make you want to indulge into it. You might, however, refrain from doing so, because eating cake might conflict with your goal of keeping your weight under control.

Stimulus-driven and goal-directed processes differ in the content of the mental representations involved. In a stimulus-driven process, a stimulus activates an association between the representation of the stimulus or stimulus features and the representation of a behavior (i.e., action tendency), which may or may not translate into overt behavior. In a goal-directed process, the represented expected utilities of different behavior options are compared and the behavior with the highest expected utility is selected. The expected utility is a function of the subjective value of the expected outcome of a behavior and the expectancy (i.e., subjective probability) that the behavior reaches this outcome (Savage, 1954/1972).

Moors et al. (2017) proposed to embed the goal-directed process in an action control cycle (Miller, Galanter, & Pribram, 1960), which starts with a comparison of a stimulus

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with a person's goals (i.e., representations of valued outcomes). If this comparison results in a discrepancy, a goal to reduce this discrepancy is activated. This reduction can be achieved either by acting on the situation in a goal-directed way (i.e., assimilation), by adjusting the goal (i.e., accommodation), or by biasing interpretation of the stimulus (i.e., immunization; Brandstädter & Greve, 1994). If the person chooses to act, an outcome is produced that forms a new stimulus that is entered in a new cycle, which is repeated until the discrepancy is resolved.

Traditional dual-process models of emotional behavior (Strack & Deutsch, 2004) typically endorse a default-interventionist architecture regarding the interplay between stimulus-driven and goal-directed processes (Moors et al., 2017). In this architecture, the stimulus-driven process starts earlier than the goal-directed process to determine the initial emotional action tendency and counts as the default determinant of behavior, whereas the goal-directed process operates only at a subsequent stage to occasionally intervene. This division of labor between both processes stems from the assumption that stimulus-driven processes are more automatic than goal-directed processes, which means that they require less time, motivation, and/or attention to operate (Moors & De Houwer, 2006; Moors, 2016).

Moors (2017a, 2017b; Moors & Boddez, 2017; Moors et al., 2017) proposed an alternative dual-process model with a parallel-competitive architecture. This model suggests that stimulus-driven and goal-directed processes can both operate automatically, which implies that they often will occur simultaneously and compete with each other to determine behavior. If they do compete, the goal-directed process should often win because goal-directed processes are more likely to reach goal satisfaction than stimulus-driven ones. In general, stimulus-driven processes should be weaker than goal-directed ones and should determine emotional behavior only in exceptional cases. This might happen, for instance, if the stimulus-driven process receives no competition from a goal-directed process.

In sum, both types of dual-process models propose that stimulus-driven and goal-directed processes can determine behavior and they both assume that overt behavior can be the result of a goal-directed process. Crucially, however, they make different predictions about the process responsible for early action tendencies. The default-interventionist model suggests that stimulus-driven processes determine action tendencies at an early stage and that goal-directed processes can only take over at a later stage. This model predicts that early action tendencies are determined by a stimulus-driven process. The parallel-competitive model, by contrast, proposes that goal-directed processes are the typical determinant of action tendencies even at an early stage and that stimulus-driven processes determine action tendencies only in exceptional cases. This model predicts that early action tendencies are determined by a goal-directed process if such a process is present, but that they can be determined by a stimulus-driven process if such a process is present but when a competing goal-directed process is absent.

The purpose of the current study was to pit the predictions of both types of dual-process models against each other. To this end, we assigned half of the participants to an experimental group in which stimuli were presented that could trigger a stimulus-driven process and in which we set up a goal-directed process that would lead to opposite action tendencies as the stimulus-driven process. We assigned the other half of the participants to a control group in which the same stimuli were presented, but no goal-directed process was set up. We examined whether the action tendency that occurred in the experimental group was the one belonging to the stimulus-driven process, as predicted by the default-interventionist model, or the one belonging to the goal-directed process, as predicted by the parallel-competitive model. Both models predicted the action tendency in the control group, on the other hand, to be the one belonging to the stimulus-driven process. According to the default-interventionist model, this process should be strong and produce detectable action tendencies. According to the parallel-competitive model, however, the stimulus-driven process should be either weak or not present at all, so that it may or may not produce detectable action tendencies.

To induce a stimulus-driven process, we relied on findings from affective compatibility research in which people are typically faster to approach positive stimuli and avoid negative stimuli (i.e., compatible trials) than to approach negative stimuli and avoid positive stimuli (Krieglmeyer, De Houwer, & Deutsch, 2013). This effect is typically taken as evidence for the existence of a stimulus-driven process in which the representation of positive/negative valence of a stimulus (S) is directly connected to the tendency to approach/avoid (R), understood as the tendency to decrease/increase the distance to the stimulus (Chen & Bargh, 1999; Markman & Brendl, 2005).[1] To set up a competing goal-directed process, we used an operant conditioning procedure, in which approaching negative stimuli and avoiding positive stimuli led to a positive outcome (money), whereas approaching positive stimuli and avoiding negative stimuli led to a negative outcome (loss of money). We chose action tendencies opposite to the action tendencies expected based on a stimulus-driven process, so that we could derive from the action tendencies whether they were caused by a stimulus-driven or a goal-directed process.

Action tendencies were measured via motor evoked potentials (MEPs) elicited by single-pulse transcranial magnetic

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[1] There also are theoretical arguments for the idea that a stimulus-driven process underlies the VAAC effect. First, the stimuli presented in these studies are pictures that are irrelevant for participants' goals (e.g., the picture of a snake does not threaten safety). Even if participants would have the "symbolic" goal to watch positive pictures, the responses in most studies have zero expectancy for reaching such a goal (e.g., avoidance does not make the picture disappear).

stimulation (TMS) over the primary motor cortex (M1). MEP amplitudes are taken as an index of the corticospinal excitability (CSE) and provide a read-out of action tendencies (Bestmann & Duque, 2016; Klein-Flügge & Bestmann, 2012).

Previous studies have used TMS to investigate the effect of stimulus valence on approach and avoidance tendencies (Coelho, Lipp, Marinovic, Wallis, & Riek, 2010; Gough, Campione, & Buccino, 2013). In most of these, action tendencies were operationalized as general or muscle-specific increases or decreases in MEPs. For instance, Coehlo et al. (2010) reported that negative stimuli led to higher MEPs than positive and neutral pictures, which they took as evidence that negative stimuli activated an avoidance tendency. It could be argued, however, that an increase in MEPs indicates general action preparation, which also characterizes other action tendencies (e.g., the tendency to approach).

To solve these ambiguities, Fini et al. (2020) first trained participants to use one specific finger to approach and another to avoid (for a similar procedure with fight/flight responses; see Moors et al., 2019). Then, participants observed positive and negative pictures followed by a TMS pulse and MEPs were measured in the finger muscles. In one study, they found higher MEPs in the approach/avoidance finger when positive/negative pictures were shown, suggesting that positive/negative pictures elicit an approach/avoidance tendency.

Other TMS studies already provided evidence that the factors of a goal-directed process have an effect on MEPs (Klein, Olivier, & Duque, 2012; Klein-Flügge & Bestmann, 2012). For instance, Klein-Flügge and Bestmann (2012) manipulated the expected utilities of two response options provided in a choice task. They found larger MEPs in the finger used for the chosen response than in the finger for the nonchosen response.

The current study goes beyond previous TMS studies on goal-directed processes in that we pit stimulus-driven and goal-directed processes involved in the tendencies to approach and avoid against each other (but see Chiu, Cools, & Aron, 2014; Moors et al., 2019). In addition, we followed Fini et al. (2020) by first setting up a connection between approach/avoidance responses and the specific muscle responses of abducting the index/thumb in a R-finger training phase. Next, participants were randomly assigned to an experimental group or a control group. In the experimental group, a goal-directed process was set up in a S:R-O training phase by rewarding participants for approaching negative and avoiding positive stimuli and by punishing participants for approaching positive and avoiding negative stimuli. In the succeeding test phase, participants followed the same instructions as during the S:R-O training phase, but a single TMS pulse was delivered 400 ms after presentation of the positive and negative stimuli and MEPs were continuously measured in the effectors of the index finger (first dorsal interosseus [FDI]) and the thumb (opponens pollicis [OP]). In addition, participants were not allowed to execute their response until a cue was presented 100 ms after the TMS pulse. Participants in the control group were not exposed to the S:R-O training phase (but received a free choice phase without rewards). During the test phase, they merely observed the stimuli.

We expect different results for the experimental group based on the default-interventionist model than based on the parallel-competitive model. According to the default-interventionist model, the stimulus-driven process will determine the early action tendencies, with positive pictures leading to an approach tendency and negative pictures to an avoidance tendency. However, according to the parallel-competitive model, the goal-directed process will determine the early action tendencies, with positive pictures leading to an avoidance tendency and negative pictures leading to an approach tendency. In the control group, both models predict that a stimulus-driven process will determine the early action tendencies with the slight nuance that the parallel-competitive model allows for the possibility that the stimulus-driven process might be too weak to be registered or might even be absent.

Method

Design and participants

The experiment had a mixed design with group (experimental, control) as the between-subjects factor and valence (positive, negative) and response (approach, avoidance) as the within-subject factors. Seventy-five right-handed participants with normal or corrected-to-normal vision were recruited through the experiment management system of the University of Ghent and were randomly assigned to either the experimental or control group. All participants were prescreened for risks associated with TMS (Rossi et al., 2009), had no history of neurological or psychiatric disorders, and gave written consent at the beginning of the study. Participants were reimbursed for their participation with 15 euro plus an additional monetary reward in the experimental group. The data of eight participants were excluded from the analysis because of invalid EMG data in more than 30% of the trials ($n = 6$), mistakes in more than 80% of the trials in the S:R-O/control training phase and more than 80% of the trials in the test phase ($n = 1$), or technical problems with the stimulator ($n = 1$). This resulted in a final sample of 67 participants with 32 participants ($M_{\text{age}} = 21.44$ years, 62.5% female) in the experimental group and 35 participants ($M_{\text{age}} = 22.06$ years, 60% female) in the control group. This sample size allows detecting a three-way interaction effect with a minimal effect size of $\eta^2_{\text{partial}} = 0.30$ according to a simulation-based power analysis using the R package ANOVA power developed by Lakens and Caldwell (2019) and statistics based on the results obtained by Fini et al. (2020).

Stimuli and procedure

Participants were seated at 60-cm distance from a 17-inch computer screen in a dimly lit room. An Azerty keyboard was positioned vertically in front of the participants with the keys "U" labeled as approach, "F" labeled as avoid, and "J" and "G" labeled as starting positions for the index finger and the thumb, respectively. Participants completed two training phases (i.e., R-finger training phase, S:R-O/control training phase) and one test phase. Randomization, stimulus presentation, TMS triggering, and RT recordings were controlled by the experiment software Affect 4.0 (Spruyt et al., 2010). We used the same stimulus set as Fini et al. (2020), which comprised positive, negative, and neutral pictures (328 x 246 pixels) selected from the International Affective Picture System (IAPS, Lang, Bradley & Cuthbert 1997) and from a new database created by Dillen (2015). All pictures depicted scenes of humans, such as a happy couple, kids playing, a person enjoying a leisure activity, a mutilated individual, injured people, and a fighting scene. We showed participants 6 positive and 6 negative pictures in the second training phase, and 45 positive, 45 negative, and 10 neutral pictures in the test phase. Within each of these phases, picture presentation order was randomized.

R-finger training phase The aim of the R-finger training phase was to set up the mapping between approach and avoidance responses and specific finger or muscle movements. This phase consisted of 30 trials. Participants positioned the index finger and the thumb of their right hand on the keys labeled as starting position of the respective finger. At the beginning of every trial, a dot and a manikin representing the participant appeared on the screen. The dot was positioned in the middle of the screen and the manikin was positioned below the dot (see De Houwer, Crombez, Baeyens, & Hermans, 2001). After 500 ms, an auditory cue was given via headphones instructing participants to either approach or avoid. If the approach cue was given, participants had to abduct the index finger from the middle finger and press the key labeled as approach. If the avoid cue was given, participants had to abduct the thumb from the index finger and press the key labeled as avoid. Correct approach/avoidance responses were followed by the manikin walking for 500 ms toward/away from the dot. Responses conflicting with the instructions were followed by an auditory error cue. The response deadline was set to 2,000 ms after the auditory cue onset. If a response was given after this deadline, the message "TOO LATE" appeared on the screen. Participants could not proceed without giving a response. Trials terminated 4,000 ms after the movement of the manikin ended. The ITI was set to 1,000 ms on average (with a range of 500 until 1,500 ms) for all training phases and the test phase.

S:R-O/control training phase The aim of the S:R-O training phase was to set up a goal-directed process in the experimental group. Participants in this group were informed that positive and negative pictures would appear on the screen together with the manikin and that they could choose to approach or to avoid the picture. Participants were additionally instructed that they would gain 5 cents if they approached a negative picture or avoided a positive picture and that they would lose 5 cents if they approached a positive picture or avoided a negative picture. This instruction together with the subsequent practice trials served to set up the goal-directed process in this group. The phase consisted of 12 trials. The number of trials was kept to a minimum to avoid inducing a new stimulus-driven process (via overtraining), while at the same time allowing participants to learn the expected utilities of the responses (as confirmed in a pilot study with 11 participants). Participants' right hand was positioned in the same way as in the R-finger training phase. Each trial started with the presentation of a positive or a negative picture together with the manikin (at the same position as in the previous phase). An auditory cue "choose" was given via headphones 500 ms after stimulus onset indicating that participants could choose whether to approach or to avoid the stimulus using the same keys and followed by the same approach or avoidance movements of the manikin as in the R-finger training phase. RTs (in ms, from the auditory cue to response onset) were recorded. After response execution, a message appeared on the screen for 3500 ms indicating whether participants had won or lost money in each trial, and a delay message if their response exceeded the response deadline of 2,000 ms after the auditory cue onset. Trials were terminated 4,000 ms after the movement of the manikin ended. Participants in the control group completed a control training phase to make sure they were still exposed to the same stimuli as participants in the experimental group. The general structure of the trials was the same as in the S:R-O training phase except that participants were instructed to freely choose whether to approach or avoid the picture and that they were not rewarded/punished for their response.

Test phase In the test phase, 90 valenced trials were randomly intermixed with 10 neutral trials (Fig. 1). The valenced trials were constructed similarly to the trials in the S:R-O/control training phase with the exceptions that (a) a TMS pulse was administered 400 ms after stimulus onset (100 ms before the auditory cue in the experimental group), (b) no delay message was displayed, (c) participants in the control group no longer received a response cue and were instructed to merely observe the presented stimuli, while keeping their fingers completely still in the starting positions. Trials were aborted 4,000 ms after the movement of the manikin ended in the experimental group and 5,500 ms after stimulus onset in the control group. The time interval between TMS pulses was at least 6,500 ms,

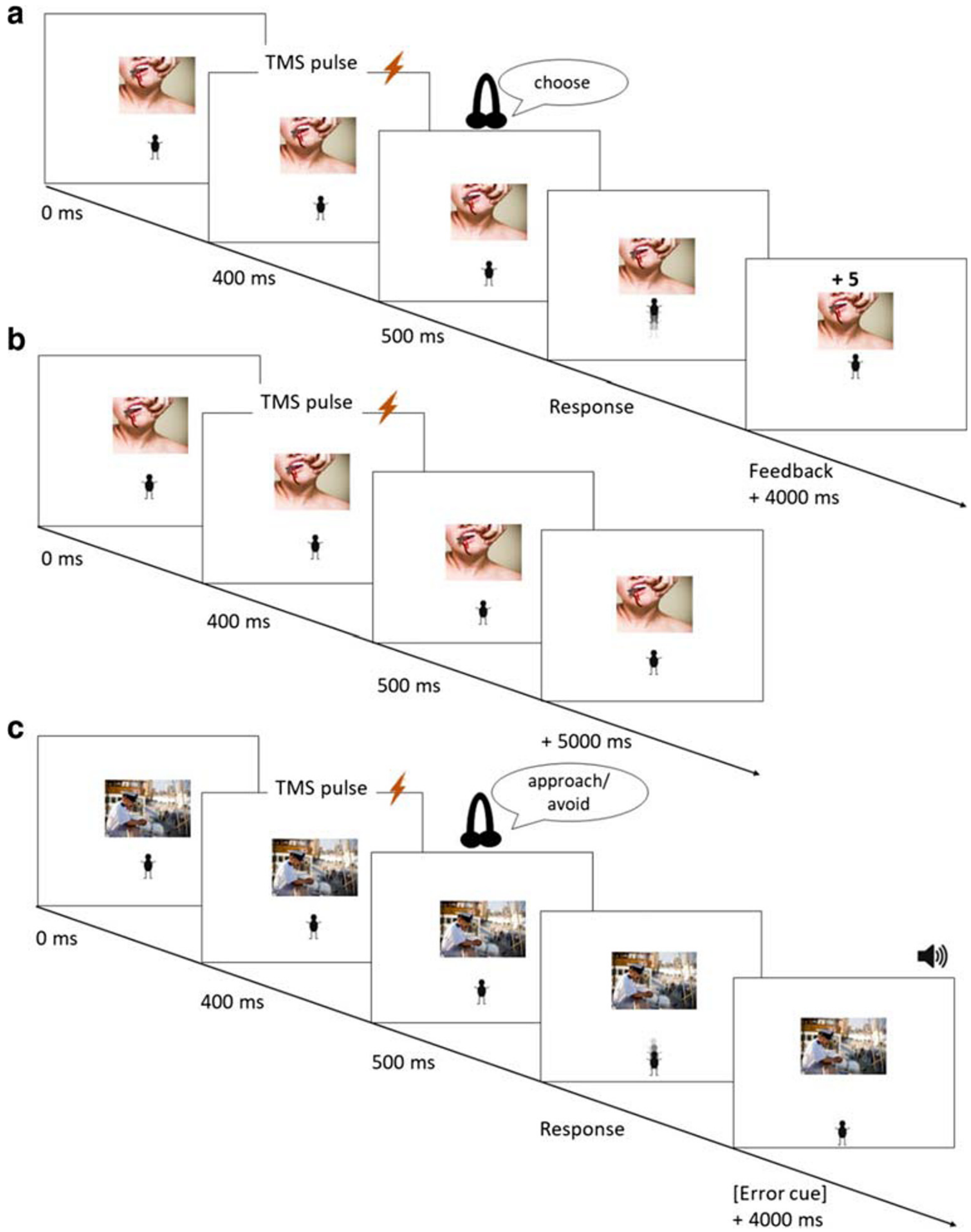

Fig. 1 Procedure of the experimental trials in the experimental and control groups. Both groups received valenced (**A/B**) and neutral trials (**C**). In all trials, a stimulus (valenced or neutral) was presented followed by a TMS pulse at 400 ms poststimulus onset. In the valenced trials in the experimental group (**A**), the auditory cue "choose" was given 500 ms poststimulus onset and the chosen response was followed by feedback on the gained/lost money in this trial. In the valenced trials in the control group (**B**), no auditory cue was given and participants merely observed the stimuli. In the neutral trials (**C**), an auditory cue to approach or avoid was given 500 ms poststimulus onset. The chosen response was followed by an error cue if the response did not match the instructions. Credits negative picture: Lotus Caroll, https://www.flickr.com/photos/thelotuscarroll/, CC BY-NC-SA 4.0; neutral picture: Davide Cassanello, https://www.flickr.com/photos/dcassaa/, CC BY-NC-ND 4.0

which corresponds to an interval for which no residual activation of a previous TMS pulse can be expected (Chen et al., 1997).

The neutral trials were the same in the experimental and the control group and were added to reconsolidate the response-finger mappings. Each neutral trial started with the presentation of a neutral picture in the middle of the screen accompanied by the manikin below the picture. The TMS pulse was administered 400 ms poststimulus onset. In contrast to the valenced trials, the pulse was followed by an auditory cue to avoid or to approach the picture 100 ms after that. Correct approach/avoidance responses were followed by the manikin walking for 500 ms toward/away from the dot. An auditory error cue was given if the response was not in line with the instruction, but no delay message was given if the response exceeded the response deadline. Participants could not proceed without giving a response. Trials were aborted 4,000 ms after the movement of the manikin ended.

TMS administration, MEP recordings, and MEP analysis

We used a 70-mm figure-of-eight coil connected to a biphasic magnetic stimulator (Rapid2; The Magstim Company Ltd.) to deliver single-pulse TMS to the left M1. The coil was positioned tangentially to the skull at an approximate 45° angle to the midsagittal plane with the handle pointing backward and held fixed by a motor arm at the optimal location to elicit MEPs in the FDI and the OP of the right hand. The location was marked on a bathing cap worn by the participants. The FDI is used to abduct the index finger from the middle finger and the OP to abduct the thumb from the index finger. The stimulation intensity was defined as 110% of the intensity of the resting motor threshold (rMT), which was determined as the intensity evoking MEPs with an amplitude larger than 50 µV in the resting FDI and the resting OP in 50% of the cases in 10 consecutive trials (Rossini et al., 2015). The average stimulation intensity was 77.67% (standard deviation [*SD*] = 9.71) of the maximal stimulator output. MEPs from the FDI and the OP of the right hand were recorded using sintered 11- × 17-mm active Ag–AgCl electrodes placed in a belly-tendon montage with ground electrodes placed at the back of the hand near the wrist. The ActiveTwo system (www.biosemi.com) was used to record the EMG signals. The signals were amplified (internal gain scaling), digitized at 2 kHz, high-pass filtered at 3 Hz, and stored on a PC for offline analysis.

Only the EMG data of the valenced trials were analyzed. Epochs were extracted 500 ms before and after the TMS pulse from the raw EMG data using MATLAB® software. MEPs amplitudes were calculated peak-to-peak for the 20-50 ms window after the TMS pulse. Trials were excluded from the analyses if there was background EMG activity 500 ms before the TMS pulse, if the amplitude was smaller than 50 µV, and if the amplitude was outside a range of ±2 SD from the participant's average amplitude. The mean percentage of excluded trials was 6% for the FDI and 9% for the OP. The raw MEPs of the FDI and the OP were standardized for each participant. Mean standardized MEPs were calculated for each stimulus valence (positive, negative) and for each response (FDI/approach, OP/avoid).

Results

Choices and reaction times

In the R-finger training phase, participants of both groups made a mistake on average in 2% (*SD* = 12%) of the trials. This suggests that participants successfully learned the response-finger mapping.

In the S:R-O/control training phase, participants in the experimental group chose on average in 98% (*SD* = 4%) of the trials a response in line with the goal-directed process (i.e., positive/negative stimulus leads to the tendency to avoid/approach; see the raincloud plot in Fig. 2; Allen, Poggiali, Whitaker, Marshall, & Kievit, 2019). This suggests that participants in the experimental group learned the S:R-O contingencies successfully and preferred to avoid positive stimuli and approach negative stimuli. This preference persisted during the test phase, as participants in the experimental group also responded on average in 98% (*SD* = 2%) of the trials in line with the goal-directed process.

In the S:R-O/control training phase, participants in the control group chose on average in 92% (*SD* = 15%) of the trials in line with the stimulus-driven process we intended to induce (i.e., positive/negative stimulus leads to the tendency to approach/avoid). This suggests that participants preferred to approach positive stimuli and avoid negative stimuli if no response instructions were given. In the test phase, choice data were not available for the control group as these participants merely observed the stimuli.

Finally, an independent sample *t*-test revealed that RTs in the S:R-O/control training phase did not differ significantly between the experimental (M = 750.73, SD = 298.33) and the control group (M = 761.67, SD = 254.82), $t(65) = 0.16$, $p = 0.872$, $d = 0.04$ (see also Fig. 3). This suggest that the operation of both processes took about equally long. In the test phase, RT data were again not available for participants in the control condition as they merely observed the stimuli.

TMS/MEP

We conducted a 2 x 2 x 2 mixed-model ANOVA with the between-subjects factor group (experimental, control) and the within-subject factors valence (positive, negative) and response (approach, avoidance). This analysis yielded no significant main effects of group, $F(1, 65) = 0.02$, $p = 0.89$, $\eta_p^2 < 0.01$, of valence, $F(1, 65) = 1.85$, $p = 0.18$, $\eta_p^2 = 0.03$, or of response, $F(1, 65) = 0.54$, $p = 0.46$, $\eta_p^2 < 0.01$. Furthermore, no significant two-way interactions were observed between group and valence, $F(1, 65) = 2.17$, $p = 0.15$, $\eta_p^2 = 0.03$, between group and response, $F(1, 65) = 0.19$, $p = 0.67$, $\eta_p^2 < 0.01$, or between valence and response, $F(1, 65) = 2.22$, $p = 0.14$, $\eta_p^2 = 0.03$. The analysis did reveal a significant three-way interaction between group, valence, and response (Fig. 4), $F(1, 65) = 12.96$, $p = 0.001$, $\eta_p^2 = 0.17$.

Planned contrasts showed that in the experimental group, MEPs following positive stimuli were stronger for avoidance ($M = 0.031$, $SD = 0.117$) than for approach ($M = -0.084$, $SD = 0.133$), $F(1, 65) = 12.17$, $p = 0.001$, $\eta_p^2 = 0.16$, but that MEPs following negative stimuli were stronger for approach (M =

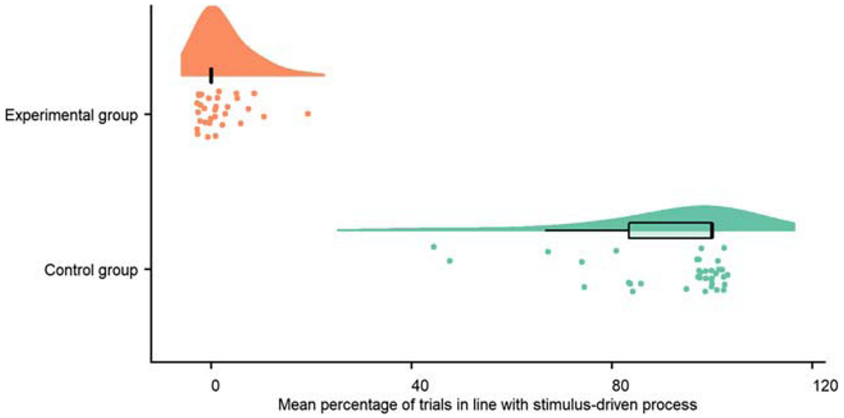

Fig. 2 Mean percentage of trials in the experimental group and the control group in line with the stimulus-driven process in the S:R-O/control training phase depicted in a raincloud plot. The raincloud plot shows a boxplot with quantile-quantile ranges in the middle, a density function above the boxplot, and the jittered individual mean percentages below the boxplot

0.083, *SD* = 0.131) than for avoidance (*M* = −0.031, *SD* = 0.120), $F(1, 65) = 12.57, p = 0.001, \eta_p^2 = 0.16$. This result is in line with the parallel-competitive model but not with the default-interventionist model. In the control group, MEPs following positive pictures did not differ significantly between approach (*M* = 0.024, *SD* = 0.110) and avoidance (*M* = −0.022, *SD* = 0.119), $F(1, 65) = 2.15, p = 0.15, \eta_p^2 = 0.03$, and neither did MEPs following negative pictures ($M_{approach} = -0.026$, $SD_{approach} = 0.107$; $M_{avoidance} = 0.023$, $SD_{avoidance} = 0.118$), $F(1, 65) = 2.51, p = 0.118, \eta_p^2 = 0.04$, although the direction of these differences followed the stimulus-driven process. This absence of significant results is still in line with the parallel-competitive model, but again not with the default-interventionist model.

In sum, in the experimental group, positive stimuli thus led to stronger MEPs in the OP (used to avoid) than in the FDI (used to approach) and negative stimuli led to stronger MEPs in the FDI than in the OP. In the control group, on the other hand, positive and negative stimuli did not lead to significantly different MEPs in the FDI and the OP (Fig. 4). These results thus show that the goal-directed process was able to determine emotional action tendencies at 400 ms post-stimulus onset. They do not show, however, that the goal-directed process was able to defeat the stimulus-driven process that we intended to induce, because they do not provide solid evidence that the stimulus-driven process was present in the first place.

Discussion

The current study pitted the predictions derived from the default-interventionist and from the parallel-competitive model against each other regarding the type of process that determines early emotional action tendencies. The default-interventionist model holds that only stimulus-driven processes can determine early emotional action tendencies. In contrast, the parallel-competitive model holds that goal-directed processes can defeat stimulus-driven processes at an early stage and hence determine early action tendencies. The results of our study supported the predictions derived from the parallel-competitive model: positive stimuli elicited a tendency to avoid and negative stimuli elicited a tendency to

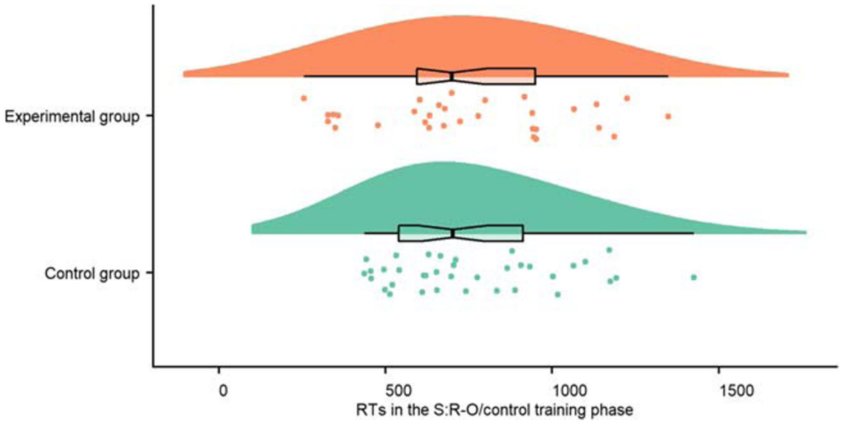

Fig. 3 Mean RTs in the experimental group and the control group in the S:R-O/control training phase depicted in a density function, a boxplot, and as jittered individual means

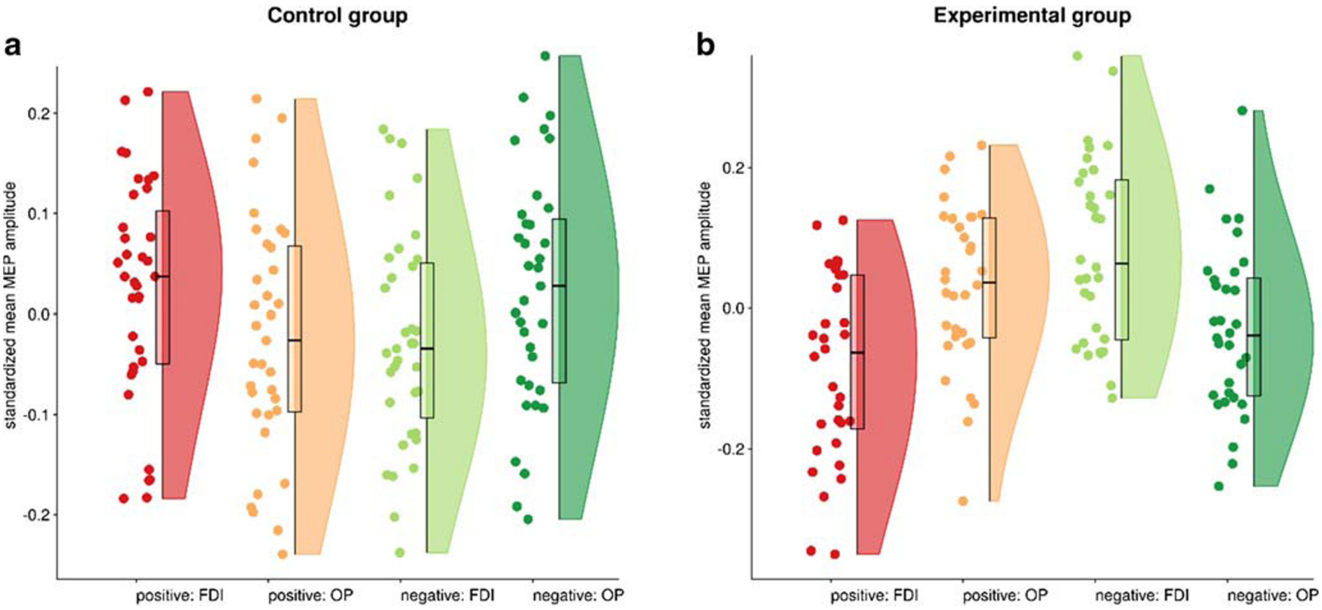

Fig. 4 Raincloud plots illustrating the standardized mean MEP amplitudes in the control group (**A**) and the experimental group (**B**) recorded from the FDI (mapped to the approach response) and the OP (mapped to the avoidance response) when presenting positive and negative stimuli. For each condition, the jittered individual mean data are depicted on the left side, a boxplot with quantile-quantile ranges is depicted in the middle, and a density function is depicted on the right side

approach. In the control group, however, we did not find support for the preexisting stimulus-driven process. Here, the MEPs did not differ significantly from each other, and therefore, we cannot be confident that the stimulus-driven process was present.

The induction of a stimulus-driven process might have been weakened by two characteristics in the design of the experiment. First, participants might have processed other stimulus features than valence, which might have created noise. Second, participants in the control condition only observed the stimuli (without responding), which might have led to reduced attention to the stimuli. It may be noted, however, that a purely stimulus-driven process should still be able to occur as it is assumed to be automatic and hence independent of the focus of attention. The results in the control condition were also at odds with the findings of Fini et al. (2020), who did obtain action tendencies in line with the stimulus-driven process. The only possible factor of difference that we see is that the current study included an additional practice phase in which participants were already exposed to positive and negative stimuli, which might have led to habituation (see also Bradley, Lang, & Cuthbert, 1993; Klein, Becker, & Rinck, 2011). Given this result, the current study does not demonstrate that goal-directed processes can defeat stimulus-driven processes at a relatively early stage. This being said, however, the study does provide convincing evidence that a goal-directed process is able to determine relatively early (400 ms) emotional action tendencies, which is in line with the parallel-competitive model and is at variance with the default-interventionist model.

This finding aligns with previous TMS studies that provide evidence that goal-directed processes can already occur at an early stage (e.g., Klein-Flügge & Bestmann, 2012). However, the current study goes beyond several previous TMS studies in terms of research questions and methods. Most studies investigated stimulus-driven and goal-directed processes separately, but did not pit them against each other (e.g., Coelho et al., 2010; Fini et al., 2020; Gough et al., 2013; van Loon, van den Wildenberg, van Stegeren, Hajcak, & Ridderinkhof, 2010). Whereas a handful of TMS studies have examined the interplay between stimulus-driven and goal-directed processes, these studies focused on a different stimulus-driven process than we did, and/or they used a method that does not allow to conclude that a goal-directed process *defeated* a stimulus-driven process (Chiu, et al., 2014; Moors et al., 2019). For instance, Moors et al. (2019) pitted a stimulus-driven process in which the representation of high/low control leads to the tendency to fight/flee against a goal-directed process in which the elicitation of fight and flee tendencies depends on the expected utilities of the behaviors. The results of the study suggested that early action tendencies were determined by the goal-directed rather than by the stimulus-driven process, in line with our results. The study of Moors et al. (2019), however, not only examined a different stimulus-driven process, it did not contain a control group in which only a stimulus-driven process was expected to operate. Therefore, it is uncertain whether the goal-directed process indeed had to compete with and defeated the stimulus-driven process.

A potential limitation of the present study might be that the timing of the TMS pulse was later than in some other studies. For instance, van Loon et al. (2010) found a difference in MEPs elicited by positive and negative IAPS pictures at 320 ms after stimulus onset, and Klein-Flügge and Bestmann (2012) observed first differences in MEPs between selected and non-selected actions from approximately 200 ms after stimulus onset. We opted for a later timing of stimulation (i.e., 400 ms) in keeping with Fini et al. (2020), because their study obtained reliable effects of stimulus valence on MEPs with a similar procedure. However, we believe there are several arguments to defend the idea that 400 ms is still "relatively" early in the context of our and Fini et al.'s (2020) study. First, the stimuli we used are more complex (i.e., scenes with humans in various situations) than those used in related TMS studies (e.g., size of shapes indicating the size of the expected reward; Klein-Flügge & Bestmann, 2012; e.g., positive or negative body postures; Borgomaneri, Gazzola, & Avenanti, 2015). The extraction of valence from complex scenes may be more time-consuming than from simple stimuli. Second, the responses we measured were more specific than those in other studies because they were associated with a higher-order meaning instead of just reflecting a general increase or decrease in MEPs (Coehlo et al., 2010) or MEPs associated with Go/No-Go decisions (Chiu et al., 2014). It might be conjectured that preparation of more specific responses is again more time-consuming than a general recruitment of activation. We acknowledge, however, that with our study we cannot exclude the possibility that a goal-directed process would have difficulty to defeat a stimulus-driven process earlier than 400 ms. It remains for future research to investigate our hypotheses with earlier stimulation timings.

As another limitation, critics might argue that the stimulus-driven process we induced was too weak—as confirmed by the results in the control group—and that it could therefore not defeat the goal-directed process. We wish to point out, however, that the alternative dual-process model does indeed hold that stimulus-driven processes are weak and therefore cannot defeat goal-directed processes. On the other hand, to conduct a fair test, we chose to induce a potentially strong stimulus-driven process. To do this, we selected a preexisting process for which empirical support is robust (Laham, Kashima, Dix, & Wheeler, 2015; Lang, Bradley, & Cuthbert, 1998; Phaf, Mohr, Rotteveel, & Wicherts, 2014) instead of setting up a new process.

The results of the current study have important theoretical implications for the explanation and the definition of emotional behavior. Traditional accounts suggest that early emotional action tendencies are determined by a stimulus-driven process (Moors, 2017a, 2017b; Moors et al., 2017; Moors & Fischer, 2019). For instance, appraisal theories propose that abstract stimulus features, such as goal in/congruence (i.e., whether a stimulus is in/congruent with a person's goals) and controllability (i.e., whether a stimulus is easy/difficult to control) are associated with specific action tendencies (Ellsworth & Scherer, 2003). However, the current study provides evidence that relatively early emotional action tendencies also can be determined by a goal-directed process as is suggested in goal-directed accounts of emotional behavior (Broekens, Jacobs, & Jonker, 2015; Moors, 2017a; Moors, 2017b; Moors et al., 2017; Moors & Fischer, 2019). Take for instance the case of a child that has a tantrum when the mother refuses to give her a cookie. In such a case, we should not only explore (abstract) stimulus features, such as goal incongruence and controllability, but also whether the child behaves aggressively, because she processes that aggressive behavior has the highest expectancy to reach her goal to get the cookie.

Conclusions

The present study investigated whether a goal-directed process can defeat a stimulus-driven process and hence determine the nature of early emotional action tendencies using single-pulse TMS. Even if our TMS results do not support the notion that a goal-directed process can literally defeat a stimulus-driven process, they do support the idea that goal-directed processes can determine relatively early (400 ms) emotional action tendencies just the same. These results are in line with the alternative dual-process model with a parallel-competitive architecture proposed by Moors et al. (2017) rather than with the traditional dual-process model with a default-interventionist architecture.

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References

Allen, M., Poggiali, D., Whitaker, K., Marshall, T. R., & Kievit, R. A. (2019). Raincloud plots: a multi-platform tool for robust data visualization. *Wellcome open research*, 4:63.

Bestmann, S., & Duque, J. (2016). Transcranial magnetic stimulation: decomposing the processes underlying action preparation. *The Neuroscientist*, *22*(4), 392-405.

Borgomaneri, S., Gazzola, V., & Avenanti, A. (2015). Transcranial magnetic stimulation reveals two functionally distinct stages of motor cortex involvement during perception of emotional body language. *Brain Structure and Function, 220*(5), 2765-2781.

Bradley, M. M., Lang, P. J., & Cuthbert, B. N. (1993). Emotion, novelty, and the startle reflex: habituation in humans. *Behavioral neuroscience, 107*(6), 970-980.

Brandtstädter, J., & Greve, W. (1994). The aging self: Stabilizing and protective processes. *Developmental review*, *14*(1), 52-80.

Broekens, J., Jacobs, E., & Jonker, C. M. (2015). A reinforcement learning model of joy, distress, hope and fear. *Connection Science, 27*(3), 215-233.

Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin*, *25*(2), 215-224.

Chen, R., Classen, J., Gerloff, C., Celnik, P., Wassermann, E. M., Hallett, M., & Cohen, L. G. (1997). Depression of motor cortex excitability by low-frequency transcranial magnetic stimulation. *Neurology, 48*(5), 1398-1403.

Chiu, Y. C., Cools, R., & Aron, A. R. (2014). Opposing effects of appetitive and aversive cues on go/no-go behavior and motor excitability. *Journal of Cognitive Neuroscience*, 26(8), 1851-1860.

Coelho, C. M., Lipp, O. V., Marinovic, W., Wallis, G., & Riek, S. (2010). Increased corticospinal excitability induced by unpleasant visual stimuli. *Neuroscience Letters, 481*(3), 135-138.

De Houwer, J., Crombez, G., Baeyens, F., & Hermans, D. (2001). On the generality of the affective Simon effect. *Cognition and Emotion, 15*(2), 189-206.

Dillen, A. (2015). IAPS 2.1. Ontwikkeling en Validatie van een Fotoset om Emoties te Induceren. Leuven: KU Leuven. Faculteit Psychologie en Pedagogische Wetenschappen.

Ellsworth, P. C. & Scherer K. R. (2003). *Appraisal processes in emotion*. In: Davidson R. J., Scherer K. R., Goldsmith H. H. Handbook of affective sciences (pp. 572-595). Oxford, UK: Oxford University Press.

Fini, C., Bardi, L., Brass, M., & Moors, A. (2020). Support from a TMS/MEP study for a direct link between positive/negative stimuli and approach/avoidance tendencies. https://doi.org/10.31234/osf.io/semv8

Gough, P. M., Campione, G. C., & Buccino, G. (2013). Fine-tuned modulation of the motor system by adjectives expressing positive and negative properties. *Brain and Language, 125*(1), 54-59.

Klein, A. M., Becker, E. S., & Rinck, M. (2011). Approach and avoidance tendencies in spider fearful children: The approach-avoidance task. *Journal of Child and Family Studies, 20*(2), 224-231.

Klein, P. A., Olivier, E., & Duque, J. (2012). Influence of reward on corticospinal excitability during movement preparation. *Journal of Neuroscience, 32*(50), 18124-18136.

Klein-Flügge, M. C., & Bestmann, S. (2012). Time-dependent changes in human corticospinal excitability reveal value-based competition for action during decision processing. *Journal of Neuroscience, 32*(24), 8373-8382.

Krieglmeyer, R., De Houwer, J., & Deutsch, R. (2013). On the nature of automatically triggered approach–avoidance behavior. *Emotion Review, 5*(3), 280-284.

Laham, S. M., Kashima, Y., Dix, J., & Wheeler, M. (2015). A meta-analysis of the facilitation of arm flexion and extension movements as a function of stimulus valence. *Cognition and Emotion, 29*(6), 1069-1090.

Lakens, D., & Caldwell, A. R. (2019). Simulation-Based Power-Analysis for Factorial ANOVA Designs. https://doi.org/10.31234/osf.io/baxsf

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). International affective picture system (IAPS): Technical manual and affective ratings. *NIMH Center for the Study of Emotion and Attention*, 39-58.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). Emotion, motivation, and anxiety: Brain mechanisms and psychophysiology. *Biological psychiatry, 44*(12), 1248-1263.

Markman, A. B., & Brendl, C. M. (2005). Constraining theories of embodied cognition. *Psychological Science, 16*(1), 6-10.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). *Plans and the structure of behavior.* New York, NY: Holt, Rinehart & Winston.

Moors, A. (2016). Automaticity: Componential, causal, and mechanistic explanations. *Annual Review of Psychology, 67*, 263-287.

Moors, A. (2017a). Integration of Two Skeptical Emotion Theories: Dimensional Appraisal Theory and Russell's Psychological Construction Theory. *Psychological Inquiry*, *28*(1), 1-19.

Moors, A. (2017b). The integrated theory of emotional behavior follows a radically goal-directed approach. *Psychological Inquiry*, *28*, 68-75.

Moors, A., & Boddez, Y. (2017). Author reply: Emotional episodes are action episodes. *Emotion Review, 9*(4), 353-354.

Moors, A., Boddez, Y., & De Houwer, J. (2017). The power of goal-directed processes in the causation of emotional and other actions. *Emotion Review*, *9*(4), 310-318.

Moors, A., & De Houwer, J. (2006). Automaticity: a theoretical and conceptual analysis. *Psychological Bulletin, 132*, 297-326.

Moors, A., Fini, C., Everaert, T., Bardi, L., Bossuyt, E., Kuppens, P., & Brass, M. (2019). The role of stimulus-driven versus goal-directed processes in fight and flight tendencies measured with motor evoked potentials induced by Transcranial Magnetic Stimulation. *PloS one, 14*(5), e0217266.

Moors, A., & Fischer, M. (2019). Demystifying the role of emotion in behaviour: toward a goal-directed account. *Cognition and Emotion, 33*(1), 94-100.

Phaf, R. H., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: a meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in psychology, 5*, 378.

Rossi, S., Hallett, M., Rossini, P. M., Pascual-Leone, A., & Safety of TMS Consensus Group. (2009). Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clinical neurophysiology, 120*(12), 2008-2039.

Rossini, P. M., Burke, D., Chen, R., Cohen, L. G., Daskalakis, Z., Di Iorio, R., …, Hallett, M. (2015). Non-invasive electrical and magnetic stimulation of the brain, spinal cord, roots and peripheral nerves: basic principles and procedures for routine clinical and research application. An updated report from an IFCN Committee. *Clinical Neurophysiology*, *126*(6), 1071-1107.

Savage, L. J. (1972). *The foundations of statistics*. New York, NY: Dover. (Original work published 1954)

Spruyt, A., Clarysse, J., Vansteenwegen, D., Baeyens, F., & Hermans, D. (2010). Affect 4.0: A free software package for implementing psychological and psychophysiological experiments. *Experimental Psychology*, *57*, 36-45.

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review, 8*(3), 220-247.

van Loon, A. M., van den Wildenberg, W. P., van Stegeren, A. H., Ridderinkhof, K. R., & Hajcak, G. (2010). Emotional stimuli modulate readiness for action: a transcranial magnetic stimulation study. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(2), 174-181.