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Support from a TMS/MEP study for a direct link between positive/negative stimuli and approach/avoidance tendencies

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Abstract

Previous behavioral studies using stimulus-response compatibility tasks have shown that people are faster to carry out instructed approach/avoidance responses to positive/negative stimuli. This result has been taken as evidence that positive/negative stimulus valence directly activates a tendency to approach/avoid, which in turn, facilitates execution of instructed approach/avoidance behavior. In these studies, however, it cannot be excluded that the results reflect a purely semantic link between stimulus valence and instructed responses. According to this alternative interpretation, positive/negative stimuli do not elicit an approach/avoidance tendency, but instead they interact with the positive/negative valence of the instructed responses, and in this way, produce the observed compatibility effect. To circumvent this possible disadvantage of compatibility tasks, we used a novel method for the measurement of early action tendencies: TMS induced MEPs. In two experiments, participants were first trained to abduct the index finger to approach and the thumb to avoid. Then, they observed a series of positive and negative stimuli. Each stimulus was followed by a TMS pulse (at 400 ms post-stimulus onset) and MEPs were measured continuously on the muscles of both fingers. These observation trials were randomly intermixed with response trials, in which neutral stimuli were presented and participants were instructed to approach/avoid the stimuli. In Experiment 1, participants received clear visual feedback on the outcome of their response in the response trials. In Experiment 2, we omitted this feedback to test whether it was necessary for the effect to occur. The results indicated higher MEPs for the approach/avoidance finger after positive/negative stimuli in Experiment 1 but not in Experiment 2. Analyses on the data aggregated over both experiments suggest that the visual feedback was necessary for stimulus valence to elicit action tendencies. Taken together, the results are in line with the results of behavioral studies with compatibility tasks, suggesting that stimulus valence directly elicits specific action tendencies already at 400 ms but they indicate that clear visual feedback is necessary for this effect to occur.

Keywords: valence, approach-avoidance, action tendencies, motor preparation, automatic, TMS

Support from a TMS/MEP study for a direct link between positive/negative stimuli and approach/avoidance tendencies

In order to deal with environmental challenges, humans perform adaptive responses allowing to obtain rewards and escape from threats. This observation has led scholars, from ancient Greek philosophy (e.g., Democritus, 460-370 BC; Aristippus; 430-360 BC, cited by Covington & Elliot, 2001) throughout the history of psychology (Arnold, 1960; Darwin, 1872; Chen & Bargh, 1999; Pavlov, 1927) to postulate that positive stimuli elicit an approach tendency, aimed at getting closer to them, whereas negative stimuli elicit an avoidance tendency, aimed at taking distance from them. Several researchers, moreover, postulate that the link between valenced stimuli and action tendencies is an automatic link (e.g., Chen & Bargh, 1999; Lang, Bradley, & Cuthbert, 1990; Neumann, Förster, & Strack, 2003; Rutherford & Lindell, 2011). This is based on the idea that stimuli activate a direct association between the representation of positive/negative stimulus valence and a representation or tendency to approach/avoid (Neumann et al., 2003). Once an action tendency is activated it may or may not translate into overt behavior (depending on other, competing action tendencies).

To test whether there is indeed a link between positive/negative stimuli and the tendencies to approach/avoid, researchers have used stimulus-response compatibility tasks in which participants were instructed to approach positive stimuli and avoid negative ones in half of the trials (compatible block), and to approach negative stimuli and avoid positive ones in the other half of the trials (incompatible block). Results typically show that participants are faster in the compatible than in the incompatible block. This effect is referred to as the valence-approach/avoidance compatibility effect (VAAC-effect; Krieglmeyer, De Houwer, & Deutsch, 2013) or the affective stimulus-response compatibility effect (e.g., Kozlik, Neumann, & Lozo, 2015). It has been observed across studies in which action tendencies of approach/avoidance were measured using different response modalities, such as pulling/pushing a joystick closer towards/away from themselves or the stimuli (e.g., Chen & Bargh 1999; Da Gloria, Pahlavan, Duda, & Bonnet, 1994; Duckworth, Bargh, Garcia,

& Chaiken, 2002; Lavender & Hommel, 2007), pressing a key to move a manikin toward/away from the stimuli (De Houwer, Crombez, Baeyens, & Hermans, 2001; Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010), nodding/shaking the head (e.g., Förster & Strack, 1996), contracting the zygomaticus/corrugator muscles of the face (e.g., Dimberg, Thunberg, & Grunedal, 2002; Neumann, Hess, Schulz, & Alpers, 2005; Neumann, Lozo, & Kunde, 2014; Otte, Habel, Schulte-Rüther, Konrad, & Koch, 2011), and full-body movements such as stepping forward/backward (e.g., Stins et al., 2011).

To add further support to the idea that the link between valence and action tendencies is direct and automatic, researchers have also reported evidence for the VAAC effect when the valence of the stimuli was task-irrelevant, and participants had to make their approach/avoidance responses dependent on a non-valenced stimulus-feature (e.g., Chen & Bargh, 1999; De Houwer et. al., 2001; Krieglmeyer et al., 2013; Neumann et al., 2005; Otte et al., 2011; Stins et al., 2011).

Early VAAC effects obtained with the joystick task were explained with a specific muscle activation account (Cacioppo, Priester, & Berntson, 2013; Chen & Bargh, 1999; Rotteveel & Phaf, 2004; Solarz, 1960) according to which positive stimuli facilitate an arm flexion movement (as involved in pulling a lever) and negative stimuli an arm tension movement (as involved in pushing a lever). Recent studies, however, were more in line with a distance regulation account (De Houwer, Crombez, Baeyens, & Hermans, 2001; Krieglmeyer, De Houwer, & Deutsch, 2011; Markman & Brendl, 2005; Seibt, Neumann, Nussinson, & Strack, 2008; Schneirla, 1959) according to which positive/negative stimuli lead to approach/avoidance tendencies understood as tendencies to decrease/increase distance irrespective of the specific muscle movements involved. In/compatibility between these action tendencies and the action tendencies induced by the instructions leads to relative inhibition/facilitation to execute the instructed action tendencies.

Another competing account, called the evaluative coding account (Lavender & Hommel, 2007; Eder & Rothermund, 2008), states that positive/negative stimuli do not spontaneously lead to approach/avoid tendencies and hence VAAC effects do not result from the in/compatibility between stimulus-induced and instruction-induced action tendencies in terms of approach/avoidance. Instead, these effects result from the in/compatibility between stimulus-induced and instruction-induced action tendencies in terms of valence. Eder and Rothermund (2008) framed inherently ambiguous movements of pulling/pushing of the joystick either as positive/negative (pulling as approach, pushing as avoidance) or as negative/positive (pulling as avoidance, pushing as approach). In support of their account, they found facilitation of responses to positive/negative stimuli when the instructed response was framed as positive/negative, regardless of the direction (pulling/pushing) of the movement. They found similar effects when pushing/pulling of the joystick was framed as up (positive)/down (negative).

Stimulus-response compatibility tasks are behavioral tasks in which participants are instructed to respond to stimuli. This method carries the risk that the compatibility effects obtained do not stem from the in/compatibility between stimulus-induced and instruction-induced action tendencies, but instead from the in/compatibility between stimulus features and features of instruction-induced action tendencies. In particular, the compatibility effect can stem from an overlap in the valence of stimuli and the valence of the instruction-induced action tendencies, for instance, via a semantic matching mechanism (e.g., van Dantzig, Zeelenberg, & Pecher, 2009; Zhang, Proctor, & Wegener, 2012). The implication is that the compatibility effect could occur even if a stimulus-induced action tendency was never activated. In other words, compatibility effects are not airtight diagnostic instruments for detecting stimulus-induced action tendencies. In order to escape from this impasse and to more directly examine whether valenced stimuli spontaneously elicit approach/avoidance tendencies, research methods are needed in which the role of instructions is minimized.

To meet this requirement, we developed a new method based on single-pulse Transcranial Magnetic Stimulation (TMS) of the primary motor cortex (M1) and the measurement of Motor Evoked Potentials (MEPs; Hoshiyama et al., 1996; Hasbroucq, Kaneko, Akamatsu, & Possamaï 1999; Michelet, Duncan & Cisek, 2010). TMS is a non-invasive technique that uses a rapidly changing magnetic field applied to the skull to produce an electrical current in underlying neural tissue. When TMS is applied to M1, it can stimulate the cortico-spinal tract, inducing a MEP in the contralateral hand (a peak in EMG activity 20 to 50 ms after the pulse). The amplitude of this MEP is considered as an index of the level of excitability of the cortico-spinal tract (Rossini et al., 2015). If a stimulus (e.g., an image) activates an action tendency, this should lead to higher TMS-induced MEPs registered from the muscle that would carry that same action. This method allows the detection of action tendencies in the absence of overt behavior, and can thus be used when participants merely observe stimuli. The method is also especially suitable to probe for automatic processes (in the sense of fast, and relatively unintentional).

Prior research with single-pulse motor TMS already showed that valenced stimuli can modulate cortico-spinal excitability. Studies vary, however, with regard to (a) the nature of the stimuli presented (e.g., pictures of valence scenes: Coelho, Lipp, Marinovic, Wallis, Riek, 2010; pictures of body postures: Borgomaneri, Gazzola, & Avenanti, 2014; Borgomaneri, Vitale, Gazzola, & Avenanti, 2015; positive or negative words: Gough, Campione, & Buccino, 2013; self-experienced pain stimuli: Farina, Tinazzi, Le Pera, & Valeriani, 2003; third-person observation of pain in others: Avenanti, Minio-Paluello, Bufalari, & Aglioti, 2006, 2009; noxious stimuli: Farina et al. 2001; Tamburin et al. 2001; Urban et al. 2004; loud acoustic stimuli: Furubayashi et al. 2000; monetary rewards and punishments: Suzuki et al., 2014; Thabit et al., 2011; Vicario, Rafal, & Avenanti, 2015), (b) the task that participants have to perform on the stimuli (valence categorization: Borgomaneri, Vitale, et al., 2015; reading: Gough et al., 2013; pure observation: Baumgartner et al., 2007), (c) the time at which the TMS pulse is delivered after stimulus onset (Borgomaneri et al., 2014: 150 ms and 300 ms; Oliveri et al., 2003: 300 ms; van Loon et al., 2010: 400-500 ms; Hajcak et al., 2007: 3-5 s), and (d) the effectors from which the MEPs are registered (index finger: Coelho et al., 2010; forearm: Gough et al., 2013; thumb: Hajcak et al., 2007). Because of this variation, results have been mixed. For instance, it is unclear whether cortico-spinal modulation (decrease or increase) at various pulse timings is caused by negative stimuli (compared to positive and neutral stimuli; Schutter et al., 2008) or by both positive and negative stimuli (Hajcak et al., 2007; van Loon et al., 2010), and whether prior response preparation related to the experimental task is required (Coelho et al., 2010). Some researchers have interpreted a general decrease and increase in MEPs in terms of specific action tendencies. For instance, Borgomaneri, Vitale, et al. (2015) and Avenanti et al. (2009) have interpreted a decrease in MEPs in terms of the tendency to orient or freeze and an increase in MEPs in terms of the tendency to avoid (see also Coelho et al., 2010; Oathes, Bruce, & Nitschke, 2008). The problem, however, is that a mere decrease in MEPs would also fit with any other passive tendency (e.g., a submissive tendency) and a mere increase in MEPs with any other active tendency (e.g., an antagonistic tendency; see Moors et al., 2019). Other researchers have interpreted the increase in MEPs in specific muscles in terms of specific action tendencies. For instance, Gough et al. (2013) interpreted an increase in MEPs in the index finger to approach because it contributes to grasping, and MEPs in the forearm to avoidance because it contributes to the release of one’s grasp. The problem, however, is that grasping can also figure in avoidance (e.g., grasping an object of safety) and releasing one’s grasp can also figure in approach (e.g., releasing an object of safety to approach).

The current study went beyond previous TMS studies in that we tried to measure not just general action readiness, but the specific action tendencies of approach and avoidance (see also Moors et al., 2019, for a study in which this method was applied to the specific action tendencies of fight and flight). While previous studies have inferred the activation of specific action tendencies either from a general increase or decrease in MEPs or from MEPs in specific muscles, we opted to install the meaning of specific muscle movements by establishing connections between these movements and approach/avoidance responses during a training phase. In particular, participants were trained to use the index finger to approach and the thumb to avoid. During the experimental phase, positive and negative stimuli were presented, followed by a TMS pulse and continuous registration of MEPs. Comparison of the MEP amplitudes in the muscles used to make the muscle movements allowed us to infer which action tendency (approach or avoidance) was activated most strongly in response to the valenced stimuli.

We conducted two single pulse TMS experiments. In the first experiment, we examined whether passive observation of positive/negative stimuli led to higher MEPs in the fingers used to let a manikin approach/avoid these stimuli. The second experiment was set up as a replication of the first experiment, in which we further examined the role of action feedback in the elicitation of approach/avoidance tendencies.

Experiment 1

The experiment was presented as a multiple-trial computer game, comprised of a training phase and an experimental phase. In the training phase, participants learned to use their index finger to approach pressing one key and their thumb to avoid pressing another key. In each trial, a manikin representing the participant appeared in the lower half of the screen and a neutral dot in the middle of the screen and participants received auditory instructions to approach or avoid the dot. In the experimental phase the manikin was presented in the lower half of the screen together with a negative, positive, or neutral picture in the middle of the screen. This phase consisted of observation trials and occasional response trials. During observation trials, positive and negative stimuli were presented and participants were merely asked to observe them without moving their index finger and thumb. Each stimulus was followed by a single TMS pulse at 400 ms post-stimulus onset, and electromyogram (EMG) activity was recorded continuously from effectors of the index finger and the thumb. In the response trials, participants received an auditory instruction to approach or avoid a neutral picture at 500 ms post-stimulus onset. These trials were simply added to reactivate the meanings of the keypress responses that were installed during the first training phase.

Method

Ratings of the stimulus material, the data file of the study, and the syntax used for the analysis are available from the Open Science Framework database (URL: https://osf.io/2p8dv/).

Design and participants. The experiment had a 2 x 2 design with stimulus valence (positive, negative) and response (FDI-approach, OP-avoid) as within-subject factors. Thirty-four participants took part in the experiment. Five participants were excluded because they did not follow the instructions correctly (they talked and asked questions during the entire experiment) or due to problems in saving EMG data. Four additional participants were excluded because they had more than 2 SDs less valid MEPs than the other participants. This resulted in a final sample of 25 participants (mean age 21.33 years ± 7.15; all but 4 right handed; 14 females). To determine this sample size, we used the method of Anderson, Kelley, and Maxwell (2017), which adjusts for publication bias and uncertainty, based on the F-values, sample size, and degrees of freedom of a study by Gough et al. (2013) to make sure we were able to detect an effect with a similar effect size as theirs with a power of 80% and a significance level of .05. Gough et al.'s (2013) study was chosen as the reference point because they also measured MEPs from two muscles and also employed a 2 x 2 experimental design. Participants had no history of neurological problems or psychiatric disorders, had normal or corrected-to-normal vision, and were prescreened for risks associated with TMS (Rossi et al., 2009). The study was granted ethical approval by the Ethical Medical review board of Ghent University Hospital. Participants gave written informed consent and received a compensation of 15 euros.

TMS administration and MEP recordings. TMS pulses were delivered with a biphasic magnetic stimulator (Rapid2, The Magstim Company Ltd.). A 70 mm eight coil was held tangentially to the skull at the level of the left motor cortex with the handle pointing backward and laterally at a 45° angle to the sagittal plane. The coil was positioned in correspondence with the optimal scalp position defined as the coil location eliciting the largest and more reliable MEPs in both the right first dorsal interosseous (FDI) and the right opponent pollicis (OP). The stimulation intensity was determined based on the resting motor threshold (rMT) of both muscles, which is defined as the intensity that evokes a MEP larger than 50 μV in 50 % of the cases in FDI and OP simultaneously (Rossini et al., 2015). Participants were equipped with a swimming cap on which the optimal location for the stimulation was marked so that the experimenter could easily track the correct position of the coil. During the experiment, a mechanical arm held the TMS coil in the correct position, but the experimenter also continuously monitored the coil position during the sessions. In participants who were moving too much, the experimenter directly held the coil on the hot spot during the entire experiment. Stimulation intensity during the recording session was set to 110% of the rMT in order to evoke reliable MEPs. Average intensity was 67.78 % (range 51%-80%). Electromyographical (EMG) activity was recorded with the ActiveTwo system (www.biosemi.com). Sintered 11x17 mm active Ag-AgCl electrodes were placed over two muscles: FDI and OP of the right hand. FDI contributes to abduct the index finger from the ring finger, and OP enables to abduct the thumb away from the index finger. The active electrodes were placed over the belly of the right FDI and OP muscles and the reference electrodes over the ipsilateral proximal interphalangeal joints (belly-tendon montage). The ground electrode was placed on the back of the hand, near the wrist joint. The EMG signal was amplified (internal gain scaling), digitized at 2kHz, high-pass filtered at 3Hz, and stored on a PC for offline analysis.

Stimuli and procedure. Stimuli in the experimental phase were positive, negative, and neutral pictures, all depicting humans and sized 328 x 246 px, selected from the International Affective Picture System (IAPS, Lang, Bradley & Cuthbert 1997), as well as from a new online database created by Dillen (2015). We chose to only present pictures with humans to avoid a possible confound of animacy observed in previous research (Borgomaneri, Gazzola, & Avenanti, 2012).

Presentation of the stimuli and registration of the responses were controlled using Affect 4.0 software (Spruyt, Clarysse, Vansteenwegen, Baeyens, & Hermans, 2010). Participants were seated at a distance of 60 cm from a 17 inch computer monitor in a dimly lit room. An azerty keyboard was vertically located and two keys (an upper key “J” and a lower key “G”) were marked with a blue spot, while two other keys (key “U” left of “J”, and key “F” below “G”) were marked respectively with the labels “AP” (for approach) and “AV” (for avoidance). Participants were asked to place the tip of the right index finger on the upper key “J” and the tip of the right thumb on the lower key “G”.

The experiment was composed of a training phase and an experimental phase. The training phase consisted of 30 trials. On each trial, a white dot was presented in the middle of a black background together with an avatar (stick figure) representing the participant located below the dot (see De Houwer, Crombez, Baeyens, & Hermans, 2001). Participants wore headphones through which they received the auditory instructions to “approach” or ”avoid” 250 ms after stimulus onset. When they received the auditory approach/avoidance cue, they had to move their index finger/thumb as fast as possible from the blue spot towards the approach/avoidance key and press it. When participants pressed the approach key, the avatar moved toward the dot; when they pressed the avoid key, the avatar moved away from the dot. If participants pressed a key later than 2000 ms after stimulus onset, the error feedback “too late” was displayed on the screen. If participants pressed the wrong key, an error sound was delivered.

The experimental phase consisted of 100 randomized trials (see Figure 1). Instead of the white dot, a picture was now presented in the middle of the screen with the manikin again located below the picture. The majority of the trials (90) were observation trials. In half of them, the picture had a positive valence; in the other half it had a negative valence. The ITI was on average 1000 ms (with a range of 500 ms until 1500 ms) with an initial delay of 1500 ms. Each stimulus remained on screen for 3250 ms. A single TMS pulse was delivered to M1 at 400 ms post-stimulus onset and EMG activity was recorded continuously from effectors of the index finger and the thumb of the right hand. A small number of trials (10) were response trials, during which participants received instructions to approach or avoid the stimuli via auditory cues presented 500 ms post-stimulus onset. If participants pressed the approach/avoid key, the avatar moved toward/away from the stimulus. The pictures presented during the response trials were neutral because we wanted to avoid installing associations between positive/negative stimuli and the instructed responses. Participants also received a single TMS pulse in the response trials but these were not analyzed. Response trials were aborted 3000 ms after response execution or at 3250 ms after stimulus onset if no response was executed until then. The minimal time interval between TMS pulses was in both types of trials at least 4250 ms, which is in line with the recommendations of Rothwell et al. (1999) to use a time interval of at least 3000 ms to avoid cumulative effects. The entire experiment including the TMS/MEP preparation lasted one hour.

The stimulation timing of 400 ms post-stimulus onset used in our study was later than the stimulation timing used in certain previous studies. For instance, using a pulse timing of 150 ms post-stimulus onset, Borgomaneri, Gazzola, and Avenanti (2014) observed an increase in MEPs in the left hemisphere for negative body postures and a decrease in the right hemisphere for both negative and positive body postures. They interpreted the increase in MEPs as an avoidance response and the decrease in MEPs as an orienting response. These interpretations may not be warranted, however, because an increase in MEPs may be compatible with other “active” action tendencies (not just avoidance but also approach) and a decrease in MEPs with other “passive” action tendencies (e.g., not just orienting or freezing, but also the tendency to give in; see also Moors et al., 2019). We chose a pulse timing of 400 ms post-stimulus onset because several pilot tests suggested that this was the optimal temporal window to register motor preparation of specific action tendencies (i.e., MEPs were the highest for this stimulation timing). It is possible that this increased latency between the stimulus onset and the pulse was necessary to allow specific action tendencies to develop and not merely a general motor activation. Other relevant differences between Borgomaneri, Vitale, et al.’s (2014) and our study are the type of stimuli used. Borgomaneri, Vitale, et al. (2014) presented body postures whereas we presented pictures of complex valenced scenes with humans (e.g., in interactions). It could be that the detection of valence from body postures requires less time than from complex scenes.

Results and Discussion

The raw EMG data were processed for the observation trials only using MATLAB® software. Epochs of 1000 ms around the TMS pulse (500 ms before and 500 ms after) were extracted from the stream of data. The peak-to-peak amplitude of EMG activity for each trial was calculated for the 20-50 ms window following the TMS pulse (i.e., the common time window during which MEPs are manifested). Furthermore, trials were rejected if the background EMG activity (measured for each trial during a time window of 500 ms preceding the TMS pulse) was above 200 µV. In addition, results from participants with few valid trials (less than 2 SDs below the average number of valid trials) were excluded from the analysis. In the final sample, trials were furthermore discarded with MEPs above or below ± 2 SDs from the average MEP of each muscle in each participant. This resulted in on average 9% discarded trials in the FDI and in 6% discarded trials in the OP.

In each participant, the remaining MEPs were normalized (*z* score) separately for the two muscles (FDI and OP) to control for a priori differences in MEPs between muscles. The *z* scores were entered in a repeated measures ANOVA with as within-participants factors stimulus valence (positive, negative) and response (FDI-approach, OP-avoid). This analysis yielded a significant valence x response interaction, $F(1, 24) = 13.30$, $p = .001$, $\eta_p^2 = .36$ (see Figure 2). We performed pairwise comparisons (using a Bonferroni corrected significance level of .025) to better understand this interaction, that is, to test whether positive and negative stimuli led to different action tendencies. These comparisons revealed a higher motor responsiveness in the muscle (FDI) of the approach finger (index) ($M = 0.05$, $SD = 0.09$) than in the muscle (OP) of the avoidance finger (thumb) ($M = -0.03$, $SD = 0.10$) when presented with positive stimuli, $F(1, 24) = 12.97$, $p = .001$, $\eta_p^2 = .35$, and a higher motor responsiveness in the OP ($M = 0.02$, $SD = 0.10$) than in the FDI ($M = -0.06$, $SD = 0.09$) when presented with negative stimuli, $F(1, 24) = 10.26$, $p = .004$, $\eta_p^2 = .30$. No other effects were significant, all *Fs* < 1.38.

The results of Experiment 1 indicate that positive/negative stimuli lead to a spontaneous tendency to approach/avoid. Positive images led to higher motor activation for FDI, the index finger muscle recruited to approach, whereas negative images led to higher motor activation for OP, the thumb muscle recruited to avoid. These results support the idea that positive/negative stimuli spontaneously elicit the tendency to approach/avoid.

Experiment 2

The aim of the second experiment was twofold. First, we set out to replicate the results obtained in the first experiment. Second, we wanted to clarify the impact of the visual outcomes of the approach/avoidance responses that participants received in the response trials on the links between positive-approach and negative-avoidance. Van Dantzig, Pecher, and Zwaan (2008) proposed a motivational account in which approach/avoidance tendencies are conceived of as "flexible, action plans that are represented in terms of their effects" (p. 17). In the same vein, Krieglmeyer and Deutsch (2010) considered the effects of distance regulation as a pre-requisite for the compatibility effect to occur. Also in the evaluative coding account (Eder & Rothermund, 2008), anticipated action consequences are supposed to be involved in the generation of motor responses. An open question that is worth investigating empirically is whether valenced stimuli can elicit the tendencies to approach/avoid (in the observation trials) in the absence of visual feedback of the outcome of the approach/avoidance responses (received in the response trials).

The method was the same as in the first experiment, except for two crucial factors. First, images were presented on a horizontally-placed flatscreen monitor and participants were asked to keep the index finger and thumb of their right hand directly on the screen in resting positions. To approach and avoid in the response trials, they had to move these fingers from the resting positions to two nearby positions. Second, the approach/avoidance behaviors were not followed by a manikin walking toward/away from the stimuli during the experimental phase, so that a clear visual feedback of the outcomes of these behaviors was absent. By no longer providing this visual feedback, we could examine whether the mental representation of this outcome mediated the influence of stimulus valence on the approach/avoidance tendencies.

Method

Design and participants. The experiment had a 2 x 2 design with stimulus valence (positive, negative) and response (FDI-approach, OP-avoid) as within-subject factors. Forty-one participants took part in the experiment. Five participants were excluded because they did not follow the instructions correctly or due to problems in saving EMG data and three participants were excluded because they had less valid trials than 2 SDs below the average valid trials for all participants. This resulted in a final sample of 33 participants (mean age 24.15 years ± 2.89; all but 4 right handed; 19 females). Participants had no history of neurological problems or psychiatric disorders, had normal or corrected-to-normal vision, and where prescreened for risks associated with TMS (Rossi et al., 2009). The study was granted ethical approval by the Ethical Medical review board of Ghent University Hospital. Participants gave written informed consent and received a compensation of 15 euros.

TMS administration, MEP recordings, stimuli, and procedure. The procedure for TMS administration and MEP recordings was the same as for the first experiment. The average intensity of stimulation was 68.29 % (range 50%-84%). The stimuli were also identical to those used in the first experiment. This time, stimuli were presented on a flatscreen placed horizontally on a table. Responses were recorded via a custom-made response box that registered button presses from two FSR-sensors and transmitted them via a USB channel. The FSR-sensors were directly fixated on the monitor via double sided adhesive rings. Two resting spots equally distant from the FSR-sensors were marked with adhesive tape, one on the upper part of the screen and one on the lower part of the screen. Participants were asked to place the tip of the right index finger on the upper spot and the tip of the thumb on the lower spot. Only when they were instructed to approach/avoid (during the training phase and the response trials of the experimental phase), they had to move their index finger/thumb from their resting spot to press the FSR-sensor buttons. The training phase and experimental phase were the same as in Experiment 1, except that participants kept their hand directly on the screen. In the response trials of the experimental phase, there was the additional difference that approach/avoidance responses were no longer followed by feedback in the form of a manikin approaching/avoiding the stimulus. This feedback was still present during the training phase.

Results and discussion

The same data processing steps and filters were applied as in Experiment 1. This resulted in the removal of 6% of trials in both FDI and OP, equally distributed across conditions. In each participant, the remaining MEPs were normalized (*z* score) separately for the two muscles (FDI and OP). When positive stimuli were presented, the average MEPs were 0.02 (*SD* = 0.08) in the FDI and -0.01 (SD = .12) in the OP. When negative stimuli were presented, the average MEPs were -0.01 (*SD* = 0.07) in the FDI and 0.01 (*SD* = .11) in the OP. The *z* scores were entered in a repeated measures ANOVA with as within-subjects factors stimulus valence (positive, negative) and response (FDI-approach, OP-avoid). The analyses revealed no significant interaction between valence and response, $F(1, 32) = 2.40$, $p = .131$, $\eta_p^2 = .07$ (see Figure 2). No other effects were significant, all *Fs* < 0.42. This suggests that the direct link between stimulus valence and action tendencies that we observed in Experiment 1 is not maintained in the absence of a clear visual outcome of the responses (i.e., the walking manikin).

Results from aggregated data over both experiments and discussion

The evidence for the link between stimulus valence and approach/avoidance tendencies was only found in Experiment 1 but not in Experiment 2. To analyze whether this effect was modulated by the methodological differences between both experiments, we combined their data. A mixed-model ANOVA on the aggregated data revealed a significant three-way interaction between experiment, valence, and response, $F(1, 56) = 4.30$, $p = .043$, $\eta_p^2 = .07$, as well as a significant two-way interaction between valence and response, $F(1, 56) = 15.614$, $p < .001$, $\eta_p^2 = .22$. No other effects were significant, all *Fs* < .86. We conducted post-hoc pairwise comparisons on the three-way interaction using a Tukey-Kramer correction for multiple testing. These comparisons revealed the same pattern of findings as the analyses of the data of both experiments separately. In Experiment 1, the MEPs were significantly higher in the FDI than in the OP when positive stimuli were presented, $q(8, 56) = 5.25$, $p = .011$, $\eta_p^2 = .20$, and significantly higher in the OP than in the FDI when negative stimuli were presented, $q(8, 56) = 5.17$, $p = .013$, $\eta_p^2 = .19$. In Experiment 2, the

MEPs did not differ significantly, all *F*s < 3.17. This suggests that the visual feedback was indeed necessary for stimulus valence to elicit an action tendency.

General discussion

In two experiments, we examined whether positive/negative stimuli spontaneously elicit the tendencies to approach/avoid by using a neurophysiological technique–TMS induced MEPs—to measure action tendencies, and thereby circumventing some of the problems related to previous behavioral studies that used stimulus-response compatibility tasks. Compatibility tasks do not allow determining whether the compatibility effect is caused by feature overlap between (a) the stimulus-induced action tendencies and the instruction-induced action tendencies or (b) the stimuli themselves and the instruction-induced action tendencies. If the latter case obtains, it is possible that the stimuli never elicited any action tendencies, which makes compatibility tasks unsuitable for examining whether the mere presentation of stimuli with a positive/negative valence is sufficient to induce action tendencies to approach/avoid. This is why we turned to single pulse motor TMS induced MEPs as a method for investigation.

Previous studies using this technique inferred specific action tendencies from general corticospinal modulation (e.g., Borgomaneri et al., 2012; Borgomaneri, Vitale et al., 2015) or from corticospinal modulation in specific muscles (Gough et al., 2013). Because these inferences may not always be warranted, we chose to install the meanings of specific muscle movements during a training phase in which participants learned how to perform an approach and avoidance response (approach with index finger and avoid with thumb). After that, participants observed stimuli with a positive or negative valence while they received a single TMS pulse to M1 at 400 ms post-stimulus onset. Comparison of the peak-to-peak amplitudes of the MEPs on the muscles of both fingers (FDI on the index finger and OP on the thumb) allowed us to infer the action tendency that was spontaneously elicited by the stimuli. In the first experiment, we showed that the passive observation of positive/negative stimuli led to higher MEPs in the fingers used to let a manikin approach/avoid the stimuli. The second experiment was set up as a replication of the first experiment and to further examine the role of the representations of the response outcomes in the elicitation of approach/avoidance tendencies. In this experiment, participants held their fingers directly on a horizontally placed flatscreen and the response outcome (manikin walking towards/away from the stimuli) was no longer shown. The results of Experiment 1 were not replicated in Experiment 2, which was confirmed by analyzing the aggregated data. Taken together, the results of both experiments support the idea that stimulus valence can elicit the tendencies to approach or avoid (Krieglmeyer et al., 2011)—or any positive or negative action tendencies more generally (Eder & Rothermund, 2008)—, but that representations of clear visual action outcomes are necessary for this effect to occur.

A few potential limitations deserve attention. A first potential limitation has to do with the timing of the TMS pulse, which was later than in some previous TMS studies (e.g., Borgomaneri et al., 2014). We justified our choice (in the Method section of Experiment 1) by arguing that more time may be involved in (a) the activation of the specific action tendencies measured in our study compared to the general motor activation registered in these previous studies, and (b) the extraction of valence of the complex stimuli presented in our study compared to the simpler stimuli presented in these other studies. Future research using other techniques (e.g., EEG), however, could examine whether the effects we obtained can also be observed at earlier stages.

A second potential limitation is that we did not counterbalance the mapping between muscles (FDI and OP) and responses (approach and avoidance). There are two possibilities to control for the mapping of muscle and approach/avoidance. First, one can reverse the mapping of muscles on half of the trials. This, however, has the problem that avoidance would have to be done with the finger closest to the screen and approach with the finger farthest from the screen. This would create an unnatural mapping, which would need extensive training to overwrite the natural mapping. Alternatively, one can also place the avatar above the stimulus on half of the trials so that the thumb movement leads to approach and the index finger movement to avoidance from the perspective of the avatar. The latter approach was taken in a previous (non-reported) experiment, but the condition in which the manikin was placed above the stimulus did not yield any clear MEP differences. There are various potential explanations why this manipulation failed. First, it is possible that participants had to carry out a mental rotation before being able to process the meaning of the thumb movement as approach and of the index movement as avoidance. Such a mental rotation may have been too time-consuming to be captured with the current pulse timing of 400 ms. Alternatively, participants might have sometimes failed to take the perspective of the avatar when it was different to their own perspective and therefore sometimes responded with the “wrong” mapping. The upshot is that it is very difficult to control the mapping without introducing additional confounds.

A third potential limitation is that we stimulated the hand region of the left motor cortex for both the approach response (measured from the FDI muscle of the right-hand index) and the avoidance response (measured from the OP muscle of the right-hand thumb). Previous research has shown that approach and avoidance behavior are preferentially executed by the right and left hand respectively because of the lateralization of approach and avoidance tendencies in the brain (Maxwell & Davidson, 2007; Rutherford & Lindell, 2011; Moors et al., 2019). By assigning both responses to the same hand, we avoided potential confounds of this lateralization, but we cannot exclude that a different pattern of results would have been obtained if we would have stimulated the right hemisphere instead.

A fourth potential limitation is that our study does not allow disambiguating between the scenario in which positive/negative stimuli lead to the more specific tendencies to approach/avoid, as suggested in the distance regulation account (Krieglmeyer, De Houwer, & Deutsch, 2013) or the scenario in which positive/negative stimuli lead to the more general tendencies to engage in any positive/negative behavior, as suggested in the evaluative coding account (Eder & Rothermund, 2008). This is because we did not train participants to engage in other positive or negative behaviors (e.g., fight, praise). Future research could examine this issue further.

A fifth potential limitation is that the pictures in our study did not only differ on valence but also on arousal, with negative pictures rated as more arousing than positive pictures. It is difficult to match the pictures on their arousal level because negative pictures are typically more arousing than positive ones (see Lang, Greenwald, Bradley, & Hamm, 1993). Furthermore, negative low-arousing pictures are often related to sadness and we suspected that sadness could elicit approach tendencies. We acknowledge that this might limit the generalizability of our results to all types of negative stimuli. However, we would like to note that despite the differences in arousal, arousal is still not likely to be responsible for the effects we obtained because higher arousal should have facilitated both approach and avoidance tendencies, as these are both active action tendencies that require the mobilization of energy.

In conclusion, the present neurophysiological evidence suggests that our motor system is activated at 400 ms post-stimulus onset without instructions to move towards/away from pictures depicting positive/negative human scenes. Future studies could further examine whether these findings generalize to other or less intense stimulus material (e.g., sadness-related stimuli, facial expressions), other positive and negative action tendencies (e.g., fight, praise), and earlier pulse timings (e.g., 200-300 ms).

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FIGURES

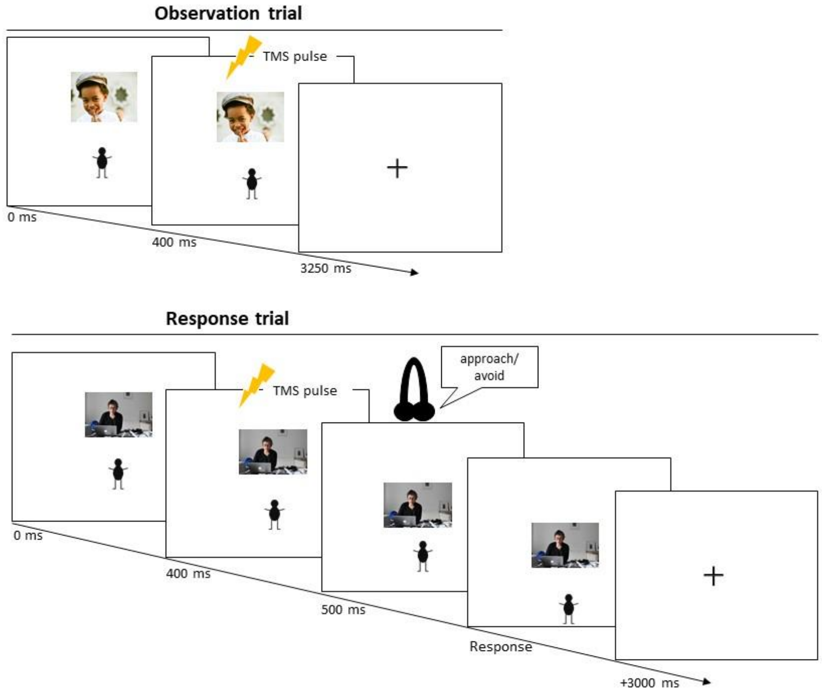

Figure 1. Sequence of events in one observation trial and one response trial. In an observation trial, a valenced stimulus was followed by a TMS pulse at 400 ms post-stimulus onset and disappeared at 3250 ms post-stimulus onset. In a response trial, a neutral stimulus was followed by a TMS pulse at 400 ms post-stimulus onset and an auditory instruction to approach or avoid the stimulus at 500 ms post-stimulus onset. The trial was aborted 3000 ms after response execution or at 3250 ms post-stimulus onset if no response was given.

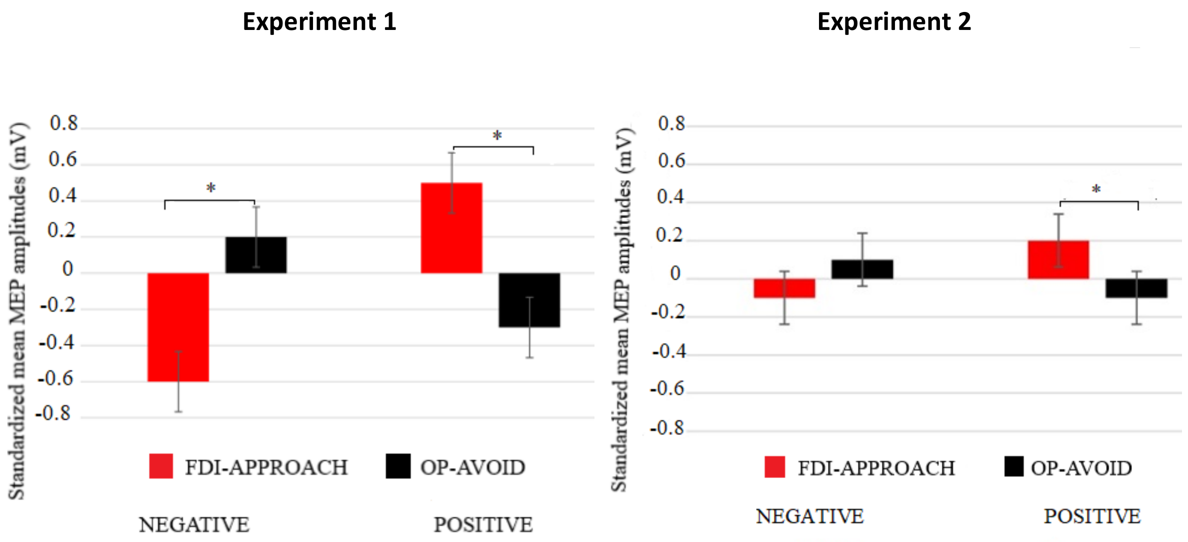

Figure 2. Average standardized MEP amplitudes in Experiment 1 and 2 for positive and negative stimuli.