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Movement-based compatibility in simple response tasks

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Previous studies reported that movement observation affected movement execution. Using one and the same set of responses (i.e., lifting or tapping the finger), correspondence effects were observed for simple responses when the go-signals were similar to the responses (i.e., movies of finger movements) but not when they were dissimilar (i.e., moving squares). The difference was attributed to a higher degree of ideomotor compatibility with visible limb movements. We tried to provide further evidence for ideomotor theory by manipulating the degree to which different responses matched one and the same set of stimuli (drifting sine-wave gratings). To this end, we measured simple reaction time of dynamic (hand movements) or static (key presses) movements in response to the onset of object motion. Object motion and dynamic responses showed ideomotor compatibility without looking alike; however, both stimulus and response involved continuous displacements. Correspondence effects were observed for dynamic responses, but not for static responses.

It is well established that latency and accuracy of manual responses are influenced by the (spatial) relation between the response and the stimulus to be responded to. Responses are faster and less error prone when for instance a left stimulus is mapped onto a left key, and a right stimulus onto a right key, than with the reversed mapping (i.e., left stimulus to right response and right stimulus to left response). The correspondence between stimulus and response (stimulus–response compatibility; SRC) affects performance even if the stimulus position is completely irrelevant for the task (e.g., Simon & Rudell, 1967). For instance, responses to the colour of a stimulus are faster when the position of the coloured stimulus corresponds to the response position.

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In most accounts SRC effects are attributed to processes of response selection (Kornblum, Hasbroucq, & Osman, 1990; Wallace, 1971; for an overview, see Lu & Proctor, 1995; Simon, 1990). In line with this hypothesis, these effects are regularly found in choice response tasks (CRT) that require participants to select one of two response keys in response to a certain attribute of a stimulus. However, no or at least no robust effects are reported in simple response tasks (SRT) that require participants to always execute the same response (e.g., a right-hand key press) to a stimulus occurring randomly on the left or right side of a computer screen (Bashore, 1981; Marzi, Bisiacchi, & Nicoletti, 1991; see Hommel, 1996, for an overview).

Some authors, for instance Brass, Bekkering, and Prinz (2001), argued that the reason why correspondence effects in SRT tasks were typically found to be small or unreliable, was that S–R arrangements with no or only little ideomotor compatibility were used in previous studies. Generally, so-called ideomotor theories on the relationship between perceived and executed actions (cf. Greenwald, 1970a, 1970b; James, 1890; Prinz, 1990, 1997) state that actions are represented in terms of the perceptual effects resulting from them. Consequently, those actions can be directly activated by a perceptual event which is similar to the effects associated with this action. Specifically, the term ideomotor compatibility was firstly introduced by Greenwald (1972) as ''the extent to which a stimulus corresponds to sensory feedback from its required response'' (p. 52) or in other words, as the extent to which a response code can be activated directly by a stimulus.

To test the hypothesis that reliable correspondence effects can be obtained in an S–R arrangement even when the response selection requirements are minimal, Brass et al. (2001) increased the ideomotor compatibility to a maximum. Their participants were instructed to always execute the same finger movement (i.e., a tapping movement with the index finger) in response to the onset of a visually presented compatible or incompatible finger movement (i.e., a lifting or tapping index finger movement; Exp. 1). Indeed, this arrangement led to a pronounced correspondence effect. That is, responses were much faster when the observed finger movement matched the executed movement than if it did not. To test whether ideomotor compatibility or plain spatial compatibility explained the effect, the authors compared finger and object movements (i.e., moving squares) within the same paradigm. In the finger movement condition the correspondence effect was replicated, but in the object movement condition no reliable effect emerged. Finally, the authors argued that possibly two separate mechanisms underlie the correspondence effect with simple responses: One related to the movement direction or to dynamic spatial compatibility; the other related to the movement type or to ideomotor compatibility.

However, a more recent study failed to find evidence for this account. In a choice response task, Bosbach, Prinz, and Kerzel (2005) asked participants to respond to the colour of a moving stimulus. The direction of motion was irrelevant, however; faster responses were obtained when the direction of target motion corresponded to the direction or position of the response (i.e., a Simon effect). Ideomotor compatibility was increased by manipulating aspects of the response, not aspects of the stimulus as in Brass et al.'s study. To this end, participants either pressed one of two buttons (''static'' response) or moved a stylus to the left or right (''dynamic'' response). The dynamic response showed more ideomotor compatibility because it involved a continuous, lateral displacement of the hand that agreed with the stimulus motion to a higher degree than the static response. Despite the different level of ideomotor compatibility, no difference in the size of the correspondence effect emerged. Thus, one may come to the rather disappointing conclusion that ideomotor compatibility only obtains if the response is made to look exactly as the stimulus (similar class identities); however, ideomotor compatibility may be absent if the similarity is varied along another dimension, such as whether stimuli and responses overlapped with respect to their position or motion.

In the present study, we continued to look for evidence for ideomotor compatibility. Instead of choice reactions, we used a simple response paradigm because we do not expect simple responses to behave exactly as choice responses. After all, Brass et al. (2001) found effects of ideomotor compatibility with simple responses. This comes as no surprise, because choice reactions involve more cognitive components than simple responses, and may have a different neural substrate (Iacoboni et al., 1999; Iacoboni, Woods, & Mazziotta, 1996). We measured simple reaction times of preinstructed finger movements in response to the onset of object movement (cf. Brass et al., 2001) and varied the overlap between stimulus and response by choosing different responses. In all cases, the stimulus was horizontal target motion. In the ''dynamic'' condition, participants were instructed to execute either a left or right lateral movement of the hand in response to motion onset. In two ''static'' conditions, participants were instructed to press a response key with their left or right hand. The dynamic condition showed a higher degree of ideomotor compatibility with respect to the similarity between stimulus and response features. Therefore, a larger correspondence effect is expected. The two static response conditions differed with respect to the distance between the response keys (small versus large). This allowed us to investigate whether the correspondence effect is modulated by the discriminability of the response keys. Presumably, the discriminability increases with increasing distance between the response keys.

EXPERIMENT

Similar to the paradigm of Brass et al. (2001), the present experiment was a simple response task, in which participants executed the same finger movement within one block of trials in response to the onset of an object movement on screen. The stimulus moved to the left or right, and left or right key presses or hand movements were used. The observed motion did or did not correspond to the to-be-executed response.

A vertical sine-wave grating served as a stimulus (cf. Bosbach, Prinz, & Kerzel, 2004). The grating was produced by modulating the luminance of successive horizontal positions in a sinusoidal manner. The resulting pattern appears as a vertical black-and-white stripe pattern with smooth transitions between black and white. The sine-wave function was multiplied with a stationary two-dimensional Gaussian function such that a circular window of the grating was visible (= Gabor patch). The horizontal position of the grating smoothly changed such that left- or rightward motion resulted. The Gabor patch appeared centrally on screen and after a random delay the grating within the patch started to move either to the left or right. Motion onset served as a go-signal for a predefined response.

In a between-subjects design we varied three response conditions. In the dynamic response condition, participants shifted the index finger of their dominant hand laterally from a home key to a target key (e.g., to the left in the first block and to the right in the second block or vice versa). In the two static response conditions, participants were instructed to press a left button with the index finger of their left hand in one block of trials and a right button with the index finger of their right hand in a second block of trials.

Method

Participants. Forty students (twelve in the dynamic response condition, twelve in the static response condition/small distance between response keys and sixteen in the static response condition/large distance between response keys) of the Ludwig-Maximilians-University of Munich were paid for participating in a single session of about 30 min. All participants reported having normal or corrected-to-normal vision, normal colour vision, and no motor impairments. None of the participants was informed in advance of the purpose of the experiment.

Apparatus and stimuli. Stimulus presentation and data acquisition were controlled by a Matrox Millennium graphics adapter on a Pentium 166 PC permitting a pixel resolution of 1280H × 1024V and were controlled by custom-written C-programs, run under the DOS-operating system. Stimuli were presented on a 21 inch screen. Displays were updated at a rate of 85 Hz. The average luminance level of the display was 10 cd/m^2. The stimulus was a Gabor patch: A sinusoidal grating with a contrast of 100% (i.e., 0–20 cd/m^2) was windowed by a two-dimensional Gaussian envelope with a standard deviation of 1°. The resulting Gabor patch had a radius of about 2° as the luminance approaches the background luminance at about two standard deviations. The

Gabor patch appeared centrally on screen and first the sine-wave grating within the patch stayed stationary, but was shown at a random phase. After a random delay between 500 and 1500 ms, the grating drifted either to the left or to the right within the stationary envelope. Spatial frequency of the grating was set to 1 cycles per degree and temporal frequency was set to 2.8 Hz (resulting velocity being 2.8°/s). In the dynamic response condition participants responded in one block of trials by shifting the index finger of their dominant hand from a home key (''period'' key of the computer keyboard) to a right target key (''slash''), and in another block of trials from the home key to a left target key (''comma''). Distance between home key and target key was ~2 cm. Reaction times (RT; i.e., interval between movement onset and release of the key) as well as movement times (MT; i.e., time between releasing the home key and pressing the target key) were measured. In the static response condition/small distance between response keys participants responded by pressing a left key (''comma'' key) with their left index finger in one block of trials and by pressing a right key (''slash'' key) with their right index finger in a second block of trials. A German QWERTZ keyboard was used. Distance between response keys was ~4 cm. Finally, in the static response condition/large distance between response keys participants responded by pressing a right key (''right cursor'' key) with their right index finger in one block of trials and a left key (''left control'' key) with their index finger in another block of trials. Additionally, the whole keyboard was moved ~24 cm to the right or left side relative to the vertical screen centre, respectively, such that the difference between both response keys was ~58 cm. The experimental setup is illustrated in Figure 1.

Design and procedure. Each experimental condition was divided into two blocks of 184 trials each. In one block, participants were required to shift the index finger of the dominant hand to the left (dynamic response condition) or to press a key with the left hand's index finger (static response condition) as soon as stimulus motion was detected. In the other block, participants were asked to shift the index finger to the right or to press a key with the right hand's index finger. Block order was balanced across participants. The experiment took place in a dimly lit room. Participants sat at a distance of about 50 cm from the computer screen with the head positioned on an adjustable chin rest. In each condition they were instructed to respond as quickly and accurately as possible to the motion onset of the stimulus, irrespective of its direction. In the static response conditions, a stationary Gabor patch appeared after an intertrial interval of 700 ms. In the dynamic response condition, observers had to depress the home key to trigger appearance of the stationary Gabor patch. After a random interval between 500 and 1500 ms the grating within the patch started to drift either to the left or to the right. We randomly varied the time interval between target and motion onset to reduce anticipation errors. The Gabor patch stayed on screen until the response was given. Responses with reaction times longer than

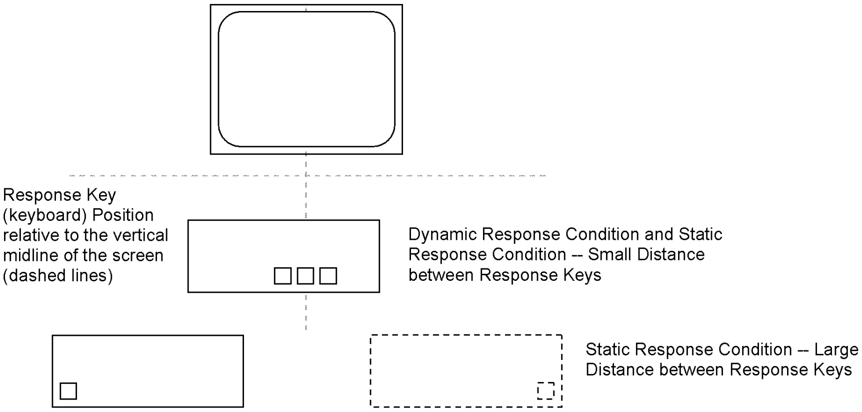

Figure 1. The experimental setups in the three different conditions. In the dynamic condition participants were required to shift the index finger of their dominant hand from a home key to a left target key in one block and to a right target key in a second block. The keyboard was placed in front of the screen such that the home key was placed along the vertical midline of the screen. In the static condition—small distance between response keys, the keyboard position remained the same and participants were asked to press the left key with the index finger of their left hand in one block and the right key with the index finger of their right hand in a second block. Finally, in the static condition with large distance between response keys, the keyboard was placed to the left (relative of the vertical screen centre) in one block and participants were required to press a left key with the index finger of their left hand. In the second block the keyboard was moved to the right side (relative to the vertical screen centre) and participants were asked to press a right with their index finger of the right hand. In each condition the stimulus appeared centrally on screen.

600 ms were regarded as missed trials, and responses shorter than 100 ms as anticipations. Executing the wrong movement (wrong direction) was counted as a movement error. These RTs were discarded from analysis. If the response was too early, too late, or wrong, auditory and visual feedback was given, while the trial was recorded and repeated at some random position in the remainder of the block. After the first experimental block, participants were given the opportunity to rest.

Results

Data analysis. In each condition direction-based correspondence was defined as follows: Trials were coded as direction corresponding when the motion direction of the target spatially corresponded to the direction or location of the response and as direction noncorresponding when the motion direction of the target spatially did not correspond to the direction or location of the response. A three-way, mixed-factors ANOVA (2 × 2 × 3) on mean RTs with direction-based correspondence (corresponding vs. noncorresponding) and experimental block (first response location vs. second response location) as within-subjects factors and response condition (static small, static large, dynamic) as a between-subjects factor was carried out. Additionally, a separate two-way repeated-measures ANOVA with direction-based correspondence and experimental block as within-subjects factors on the mean MTs from the dynamic condition was run. The results are summarised in Table 1 and 2.

In the dynamic response condition, movement error rate was 0.2%, rate of anticipations and missed trials 4.9%. In the static response condition/small distance between response keys movement error rate was 0.02%, rate of anticipation and missed trials 3.1% and finally, in the static response condition/ large distance between response keys error rates were 0.03% and 4.1%, respectively. These trials were excluded from further analyses.

Reaction time analyses. The ANOVA revealed no main effect for direction-based correspondence, $F(1,37) = 0.04$, $p = .851$, but a significant interaction between direction-based correspondence and response condition occurred, $F(2,37) = 4.79$, $p = .014$, indicating that direction-based correspondence depended on the response modality. *T*-test revealed a significant direction-based correspondence effect in the dynamic response condition, $t(11) = 3.59$, $p = .004$. Responses were faster when the direction of motion corresponded to the movement direction of the response than when it did not (348 vs. 343 ms). A significant correspondence effect was confirmed either in the static response

TABLE 1
Mean reaction times (RTs, in ms) and movement time (MTs, in ms) as a function of movement-based correspondence

	Movement-based correspondence		
	Noncorrespondence	*Correspondence*	
Condition	*MT*	*MT*	*ΔMT*
Dynamic	97	98	−1
	RT	*RT*	*ΔRT*
Dynamic	348	343	5
Static small	306	310	−4
Static large	338	338	0

Means are shown for the dynamic response condition (dynamic), static response condition—small distance between response keys (static small), and for the static response condition—large distance between response keys (static large). Note that only the dynamic response condition allows for the analysis of movement times.

TABLE 2
Mean reaction times (RTs, in ms) and movement time (MTs, in ms) as a function of block and movement-based correspondence

	Block					
	Block 1 *Movement-based compatibility*			*Block 2* *Movement-based compatibility*		
	Noncorrespondence	*Correspondence*		*Noncorrespondence*	*Correspondence*	
Condition	*MT*	*MT*	*ΔMT*	*MT*	*MT*	*ΔMT*
Dynamic	94	93	1	100	102	−2
	RT	*RT*	*ΔRT*	*RT*	*RT*	*ΔRT*
Dynamic	341	340	1	355	346	9
Static small	307	314	−7	304	307	−3
Static large	336	340	−4	340	335	5
Mean	329	332	−3	334	330	3

Means are shown for the dynamic response condition (dynamic), static response condition—small distance between response keys (static small), and for the static response condition—large distance between response keys (static large), as well as averaged across the dynamic and both static response conditions (mean). Note that only the dynamic response condition allows for the analysis of movement times

condition/small distance between response keys, $t(11) = -2.39$, $p = .036$. However, contrary to the dynamic response condition, responses were faster when the direction of motion did *not* correspond to the movement direction of the response than when it did (306 vs. 310 ms). In the static response condition/large distance between response keys no significant correspondence effect was found, $t(15) = 0.20$, $p = .842$. Finally, the ANOVA revealed a significant interaction between direction-based correspondence and block, $F(1, 37) = 5.45$, $p = .025$. In all response conditions, the direction-based correspondence effect was larger by 6 ms in the second block compared to the first (cf. Table 2). Finally, mean reaction times differed between the three experimental groups, $F(2, 37) = 3.40$, $p < .05$. Mean RTs were 308 ms with static responses and a small distance between the response keys, 338 ms with static responses and a large distance between the response keys, and 346 ms with dynamic responses. However, post-hoc Scheffé tests did not reveal significant pairwise differences between the groups (ps > .06). No further significant main effects or interactions were found (Fs < 1).

Movement time analyses. The ANOVA revealed no main effect for direction-based correspondence, $F(1, 11) = 1.69$, $p = .689$, but a significant main effect for experimental block occurred, $F(1, 11) = 6.83$, $p = .024$. MTs were shorter in the first than in the second block (93 vs. 101 ms). Additionally, the interaction between direction-based compatibility and experimental block reached significance, $F(1, 11) = 5.68$, $p = .036$ (cf. Table 2).

Discussion

The general aim of the present study was to investigate whether the size of stimulus–response effects in a simple response task may be affected by ideomotor compatibility of the response. First, we observed a reliable correspondence effect in reaction times with dynamic responses. When participants responded to a left- or rightward drifting sine-wave grating in a stationary Gaussian window by laterally shifting their index finger, a numerically small but significant correspondence effect was found. That is, rightward responses were faster when the grating drifted to the right and leftward responses were faster when the grating drifted to the left.[1] This result replicates the study of Brass et al. (2001) who reported a correspondence effect for simple responses with a dynamic stimulus. However, the stimulus did not resemble the response in the present case at all. If analysed in terms of separable dimensions, there would be no similarity along the dimension ‘‘identity’’ of stimulus and action effects. In contrast to the movies of finger movements used by Brass et al., the sine-wave gratings did not belong to the same object category as the executed finger movements. Thus, the stimulus does not have to be a one-to-one replica of the action effect for SRT-correspondence effects to occur (i.e., movies of hand movements and executed hand movements). Rather, there was similarity along another dimension: Stimulus and response involved continuous, lateral position shifts. This feature was shared when lateral movements of the hand were used, but not when ‘‘static’’ button presses were used. Strictly speaking, these findings are evidence that the distinction between spatial and ideomotor compatibility is not justified: Even in a less realistic stimulus–response environment, participants generate a response image (which is equivalent to an automatic response activation) while watching a stimulus with certain features. However, this response image is characterised by abstract features and is therefore less complete than a response image, which is generated on the basis of observing a real body movement. In other words, we would argue that spatial and ideomotor compatibility do not describe different mechanisms but belong to a continuum of similarity between stimuli and responses. That is, spatial compatibility could be considered as an instance of ideomotor compatibility. While spatial compatibility effects occur in situations where stimuli and responses share single

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[1] In line with Rubichi, Nicoletti, and Umiltà (2000), no reliable correspondence effect in movement times emerged. This finding could be regarded as evidence that participants used a certain response strategy and that the correspondence effect in RTs is due to facilitation components (for an elaborated discussion on the occurrence of correspondence effects in MTs vs. RTs, cf. Rubichi et al., 2000).

abstract features, for instance, ''left'' or ''right'', ideomotor compatibility effects occur in situations, in which a ''quasi-imitative S–R arrangement'' (Brass et al., 2001, p. 19) is used and thus, one does what one sees. In other words, in the latter case, the stimulus shares more properties with the sensory feedback of the response which leads to a stronger response activation and a more pronounced compatibility effect than a response image which is based on simple spatial features of the stimulus. Nevertheless, in both cases, the same mechanism is effective, namely an automatic response activation by certain properties of a stimulus (see below).

To our surprise a reversed correspondence effect was found in the condition in which participants responded ''statically'' by pressing a left key in one block of trials and a right key in another block of trials. That is, left key presses were facilitated when the grating drifted to the right and right key presses were facilitated when the grating drifted to the left. This result clearly shows that the degree of overlap between stimulus and response affected the correspondence effect. In fact, the condition with low and high ideomotor compatibility produced correspondence effects in the opposite directions.

The reason for the reversal of the effect is not entirely clear. It may be possible that the stimulus was coded in a different manner depending on what the response was. Different aspects of a moving stimulus may be coded: The direction of motion, the starting point, and the endpoint (because the patch itself did not move, start- and endpoint refer to the single ''stripes'' in the grating). Notably, the starting point was always opposite to the direction of motion. In a previous paper, we argued that the starting position of a stimulus is important for the coding of motion (Bosbach et al., 2005). It may be that simple responses emphasised coding of the starting position over coding of the movement direction. From the perspective of ideomotor theory, the reason for the dominance of position codes with ''static'' responses is that responses were defined by their position, not by horizontal motion. Therefore, similar positions (not position changes) are expected to activate the response. Yet it remains to be explained why the starting point and not the endpoint was coded. Future research will have to determine the exact conditions that determine coding of the start or end position.

However, in the second static response condition, in which the lateral position of the left and right response key was increased, no significant correspondence effect occurred. This finding rules out the explanation that the reversed compatibility effect in the static condition with small distances between response keys is due to reduced discriminability between the left and right response key.

Further, our results show that for correspondence effects to emerge in a simple response task, the alternative response has to be cognitively present or activated. Correspondence effects were more pronounced after observers finished the first block of trials and switched to the second block that involved the alternative response. These findings are consistent with Hommel (1996) who reported that simple effects would only emerge if the participants occasionally switched to the response alternative or at least if both response alternatives are cognitively represented. Unfortunately, Brass et al. (2001) did not evaluate whether their correspondence effect increased after participants switched from the first response (or block) to the alternative response. Thus, we cannot answer the question whether stronger ideomotor compatibility would eliminate the need for activating the second response.

In the literature, spatial correspondence effects in simple response tasks are typically reported to be of small size compared to those effects in choice response tasks. The difference in size in SRT versus CRT has led to the assumption that each effect has different origins (cf. Hommel, 1996, for an extended discussion on this point). Effects in CRT are most often attributed to interactions of stimulus and response codes at the level of S–R translation. However, in a SRT task the stimulus does not need to be translated and a response does not need to be selected. How then can correspondence effects in SRT be explained? Our findings point to an explanation in terms of the ideomotor theory, namely, that the motion direction automatically activated a corresponding response on the basis of similarity between the stimulus and the to-be-executed response (cf. Hommel, 1997, 1998; Kornblum et al., 1990; Prinz, 1990). The automatic response activation was restricted to a situation in which stimulus and response shared the feature ‘‘continuous lateral position change’’. This was the case for lateral hand movements, but not for static key presses with the left or right hand. However, as mentioned in the introduction and contrary to the present finding, we did not observe that dynamic responses which involved lateral displacements of the hand were more affected by a moving stimulus than static key press responses when participants performed a choice response task (Bosbach et al., 2005). How can this difference be explained? In a choice response task, participants possibly based their responses on an abstract criterion like ‘‘left’’ or ‘‘right’’. That is, independent of whether the response mode was dynamic (i.e., lateral shifting movement of the hand) or whether it was static (i.e., left or right button press without changing the horizontal position of the hand), the distinction between both responses was only made on the basis of ‘‘left’’ or ‘‘right’’ and not on the basis of ‘‘to the left/right’’ or ‘‘on the left/right’’. In other words, motion direction and position may be represented as rather abstract ‘‘left’’ and ‘‘right’’ codes that interact at the level of response selection and result in a SRC effect. This idea was also supported by the finding that even high-level motion stimuli produced a Simon effect. That is, motion that cannot be derived from low-level motion cues, such as point-light walkers, produced effects on choice RTs (Bosbach et al., 2004). In a similar vein, Proctor, Wang, and Vu (2002) concluded that conceptual and not perceptual similarity between stimuli and responses is responsible for SRC effects.

Contrary, in a simple response task participants have to execute a predefined response only. This is cognitively less demanding than a choice response task. Thus, participants can fully concentrate on the stimulus presented to them and it may be that the stimulus is coded in an analogue (nonabstract) fashion and may activate the response via perceptual induction (cf. Knuf, Aschersleben, & Prinz, 2001; Prinz, de Maeght, & Knuf, 2005). Perceptual induction describes the principle that an observer ''tends to repeat in her actions what she sees happening in the scene'' (Prinz, 2002, p. 157). Perceptual induction becomes effective because stimuli and responses are represented in a common representational domain such that seeing a particular stimulus event may automatically activate a similar motor event (cf. ideomotor theory). Therefore, responses that are similar to the stimulus are executed faster because perceptual and motor processes use the same code (cf. Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990, 1997). In other words, in our simple response task the stimulus automatically induced the production of a similar action or an action which has similar perceivable effects (cf. ideomotor movements; Prinz, 1987). In this case, similarity would be defined along the dimension ''continuous lateral position change''. For choice response tasks, the relation between stimuli and responses may be more complex and probably relies on different, more abstract codes.

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