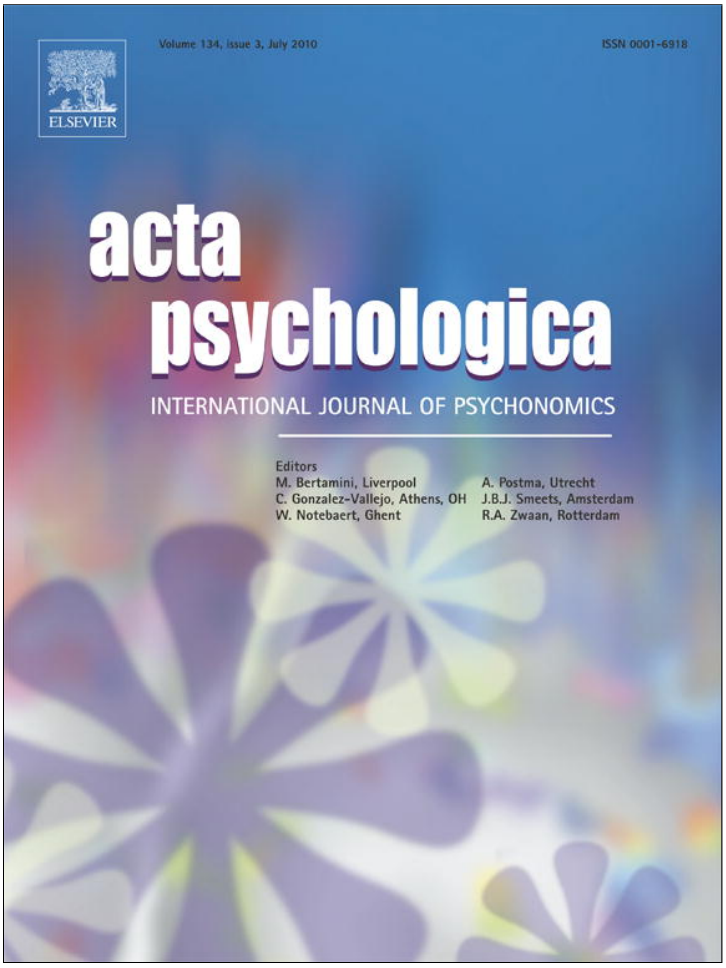
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What part of an action interferes with ongoing perception?

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ABSTRACT

Recent studies have demonstrated specific interference effects between concurrent perception and action. In the following we address the possible causes of such effects by employing a continuous paradigm in which participants were asked to produce movements in a specified direction and to judge the direction of a concurrently presented stimulus motion. In such paradigms, a repulsion of the perceived by the produced movement direction is typically observed. The first question addressed in the current study was whether passive displacements of the hand would be sufficient for inducing the repulsion effect. This was done by sometimes moving the participants' hands with a robot. No repulsion effect was found for these passive movements, which shows that the integration of visual and proprioceptive information is not sufficient for repulsion to arise. However, repulsion was present for active movements, that is when participants intended to move. In a second experiment, participants' movements were sometimes unexpectedly blocked by a robot. No repulsion was observed in the blocked condition. We conclude that the intention to move (Experiment 1) and actual movement execution (Experiment 2) are both necessary preconditions for this type of specific interference to arise in continuous and concurrent perception–action tasks.

People perform concurrent tasks in many everyday situations, such as driving while listening to music or a passenger. Intuitively, many people would agree that not only dual-tasking *per se* can hamper performance but also that the content of each task is critical as well. That is, if two tasks share common features (e.g., spatial information), most people would expect the tasks to interfere to a larger extent than when they do not share features. For example, hearing the word "right" should interfere more with steering behavior than hearing a word that has no relation to driving. Indeed, changes in performance that arise when features (i.e., the content) of two tasks overlap and do not overlap have been labeled *specific* and *unspecific* interference, respectively (Müsseler, 1999).

The last decade has seen an increase in the investigations of specific interference effects in dual-task situations (Hamilton, Wolpert & Frith, 2004; Lindemann, Stenneken, van Schie & Bekkering, 2006; Repp & Knoblich, 2007; Schubö, Aschersleben & Prinz, 2001; Schubö, Prinz & Aschersleben, 2004; Wohlschläger, 2000; Zwickel, Grosjean & Prinz, 2007; Zwickel, Grosjean & Prinz, 2008). Two types of specific interference have been observed. *Assimilation* is said to occur when overlapping features are enhanced, thereby leading to an attraction between what is perceived and produced. The attenuation of overlapping features is thought to lead to *contrast*, which results in a repulsion between perceived and produced events. In particular, contrast effects (CEs) have generally been found when the two tasks were

a) functionally unrelated, in that what was perceived did not specify what action needed to be produced (e.g., Schubö et al., 2001; cf. Chua & Weeks, 1997; Ehrenstein, Cavonius & Lewke, 1996)
b) performed concurrently (e.g., Hamilton et al., 2004; Zwickel et al., 2008; cf. Kerzel, 2001), and
c) did not involve ambiguous stimuli (e.g., Schubö et al., 2004, Zwickel et al., 2008; cf. Repp & Knoblich, 2007; Wohlschläger, 2000).

Hamilton et al. (2004), for example, showed that participants judge the weight of objects lifted by actors as being heavier when they concurrently hefted light as opposed to heavy weights themselves. Similarly, Schubö et al. (2001, 2004) demonstrated that the amplitudes of stimulus motions were perceived as larger during the production of small- compared to large-amplitude hand movements. CEs in directional judgments were demonstrated by Zwickel et al. (2008). In their task, participants produced hand movements in certain directions while observing independent stimulus motions that also varied in direction. Perceptual judgments on a subsequent test stimulus revealed that the perceived directions were repulsed by the produced directions. Horizontal stimulus motions, for example, were judged as moving more upward after having produced downward as opposed to upward hand movements (for an online measure of this effect, see Zwickel et al., 2007).

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These types of CEs constitute perceptual instances of stimulus response compatibility effects (Kornblum, Hasbroucq & Osman, 1990) and have been attributed to the partial inhibition of distributed representations used by perception and action (Hamilton et al., 2004; Schubö et al., 2001; Zwickel, Grosjean & Prinz, 2010). Specifically, if both events rely on a common dimension (weight in Hamilton et al., 2004, amplitude in Schubö et al., 2001, or direction in Zwickel et al., 2008), shared features along that dimension become inhibited, leading to a repulsion between the two representations. For example, the distributed representation of a horizontal stimulus motion contains some amount of upward and downward features in addition to horizontal ones. If a downward hand movement is concurrently produced, the downward features it shares with the representation of the stimulus motion will be suppressed. This will lead to the stimulus motion being perceived as more upward than it actually was.

What has yet to be considered in this line of research is what part(s) of an action cause(s) these CEs in perception. The following two experiments addressed this question. Experiment 1 investigated how precise directional movement planning needs to be and whether proprioception of hand displacements is sufficient for a CE to occur. To this end, participants either freely moved a hand-held stylus along an earlier practiced trajectory (unconstrained condition), produced the movement by moving the stylus within a slit (constrained condition), or had their hands transported along the same trajectory by a robot (passive condition). Similar to Zwickel et al. (2008), participants were asked to report the direction of a concurrently presented and independent stimulus motion by performing a perceptual judgment on a subsequent test stimulus. If precise directional planning plays a critical role, then the CE should be larger for the unconstrained than for the constrained condition. Moreover, if the CE merely reflects a form of integration of visual and proprioceptive information, then the passive condition should lead to a repulsion effect as well.

The aim of Experiment 2 was to establish whether intending to move is sufficient to produce a CE. This question was addressed by having participants produce constrained movements and then unexpectedly blocking their hand with a robot on randomly selected trials. If intending to move is enough to cause interference, then a CE should be present independent of whether participants are able to move or not. A second goal of this experiment was to test whether the amount of effort involved in producing the movement modulates the size of the interference effect. An influence of motor effort on visual perception has been found before. For example, Witt, Proffitt and Epstein (2004) reported that the judged distance of a target increased with the weight of balls participants were asked to throw prior to making their judgments. In the current task, effort was manipulated by varying how much the robot resisted the participants' movements, and thus how much force was needed to move. Participants could only detect the amount of resistance when they tried to move, so they had to adjust the amount of force on the fly. Given the reported influence of effort on perception one could speculate that in the current paradigm an increase in effort could be associated with an increase in the activation level of the representation of the movement. This could increase the number of features of stimulus representation that are inhibited and thereby produce a stronger influence of action on motion perception.

1. Experiment 1

In Experiment 1, participants were asked to move a hand-held stylus in a specified direction either without external aid (unconstrained condition), within a slit (constrained condition), or their hands were passively transported while they held the stylus within the slit (passive condition). Concurrent with these movements a stimulus motion was shown whose direction had to be subsequently judged. If the CE is (merely) caused by the crossmodal integration of proprioceptive and visual signals, then a CE should be found in the passive condition. The potential role of precise directional planning should reveal itself in differences between the constrained and unconstrained conditions, with a larger CE arising in the unconstrained condition.

1.1. Method

1.1.1. Participants

Twenty-four right-handed individuals (mean age = 26 years; 8 females) participated in the experiment. In this as in the following experiment no visual or motor impairments were reported by the participants, all of them were naive as to the purpose of the study and received a monetary reward for their participation.

1.1.2. Stimuli, movements, and apparatus

Stimulus presentation and movement recording were controlled by an IBM-compatible PC running a program written in Pascal. The to-be-judged stimulus motion consisted of a red circle (6 mm in diameter, about 0.57° of visual angle) that moved on a black background for 1000 ms over a distance of 18 cm. The starting position of the red circle was horizontally centered and shifted 6 cm below the horizontal midline of a 21 in. monitor. Fig. 1 (top left) shows the two possible motion directions. The motions were either 4° to the right or left of the (virtual) vertical, depicted by the broken line in the middle of the displays. The test stimulus rotated back and forth within an interval of 15° around the vertical by 0.2° every 14 ms. The side on which the test stimulus initially appeared was balanced within blocks. To produce the test stimulus, five red circles (the same as for the stimulus motions) were equidistantly spaced on the trajectory that would have been followed by a motion at the respective angle. During the presentation of the rotating test stimulus, participants pressed a button on a custom-made response box with their left (non-moving) hand to indicate the perceived direction of the previously seen stimulus motion.

Participants produced the required movements with their right hand on a graphics tablet (Wacom Ultrapad A3E) that sampled the coordinates of a hand-held stylus at a rate of 70 Hz. The tablet was horizontally centered and placed below the monitor. A board prevented participants from seeing their hand. Participants were asked to produce straight-line trajectories 60° to the left or right of the (virtual) vertical (see Fig. 1). Depending on the movement condition, these movements had to be produced either without external guidance (unconstrained condition), by moving the stylus within a slit fixed to the graphics tablet at an angle of ±60° (constrained condition), or by holding the stylus within the slit and resting their hand on a board that was moved by a motor (passive condition).

1.1.3. Design

Each combination of movement direction (left and right) and movement condition (unconstrained, constrained, and passive) was administered for 2 consecutive blocks. Within a block of 24 trials, a random half of the stimulus motions deviated 4° to the left and the other half 4° to the right of the virtual vertical. In total, each participant performed 288 trials. The order of the movement conditions was counterbalanced across participants as was the order of movement directions within each movement condition.

1.1.4. Procedure

Prior to the first block of all conditions, participants practiced the required movement of the following 2 blocks. To this end, the required and actually produced trajectories were overlaid on the screen. Because the movements were more difficult to perform in the unconstrained condition, in addition to this training 5 further training trials were administered prior to the second block. No visual feedback of the produced trajectory was given during experimental trials.

In experimental trials, participants produced the required movements in one of the three movement conditions. At the beginning of each trial a small white cursor provided visual feedback of the stylus

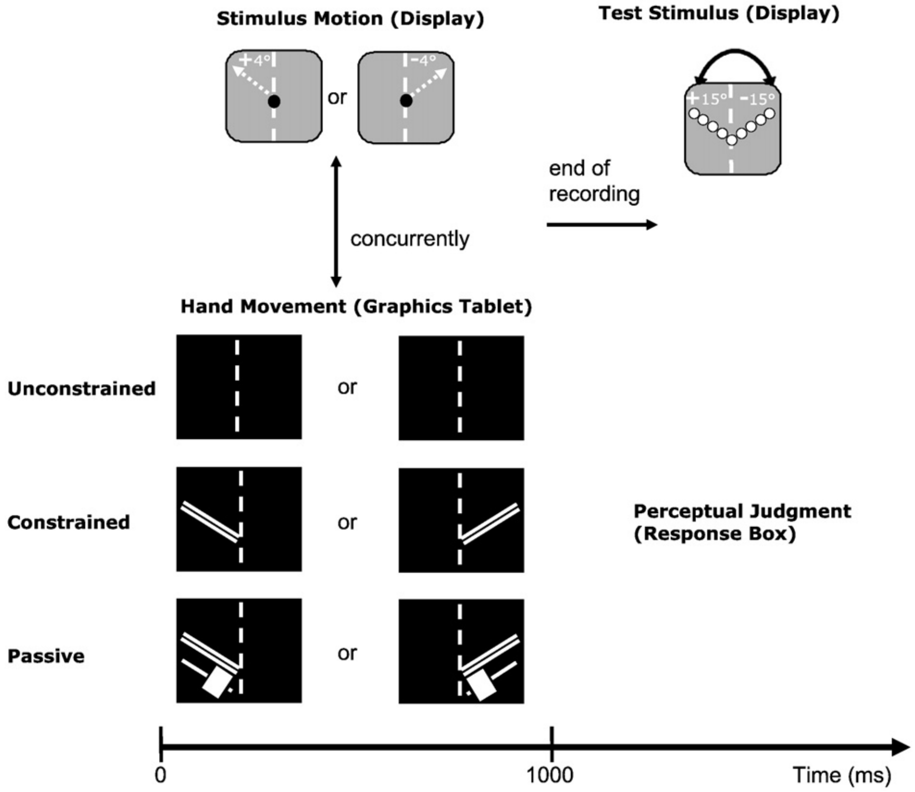

Fig. 1. The upper half shows the two possible stimulus motions on the display, the lower half the three different movement conditions. The virtual vertical is depicted by a broken line in the middle of the display/graphics tablet. This line is only drawnfor the purpose of illustration and was not visible during the experiment. Angles are also exaggerated for better visibility. In each movement condition, participants were asked to produce straight-line hand movements that deviated 60° to the left or right of the vertical. In the unconstrained condition, participants moved a hand-held stylus without any guidance. In the constrained condition, a slit was placed on the graphics tablet at the required movement angle and participants moved the stylus within it. In the passive condition, participants held the stylus within the slit and placed their hand on a board (depicted by a tilted rectangle) that was moved by a motor. After movement recording, participants stopped a rotating line (test stimulus) with a button press when they thought it matched that of the stimulus motion.

position. To start the movement, participants moved the cursor within the circle situated at the start position of the stimulus motion (see Fig. 1). A tone (1760 Hz, 15 ms) signaled one second later that the movement could be initiated. As soon as the stylus moved out of the starting circle, the stimulus motion started its trajectory, the cursor disappeared and movement recording began. The motion ended 500 ms later, the display was cleared and a 880 Hz tone (15 ms) signaled to the participants that their movement should come to an end. Movement recording lasted for further 500 ms till a third tone of 440 Hz (15 ms) was played. This was followed by the test stimulus and participants were instructed to press the response button when the test stimulus matched the perceived angle of the previous stimulus motion. After the response the screen went blank. If participants lifted the stylus, reversed movement direction, or moved after the third tone an error message to that effect was shown. The next trial started after a 1000 ms interval.

1.1.5. Data analysis

Tangential velocity profiles were calculated by numerical derivation of the movement trajectories. The first time tangential velocity reached 5% of peak tangential velocity was used as the onset time of the movement. Similarly, movement offset time was taken to be the first time after the peak that tangential velocity dropped below 5%. The stylus coordinates at these temporal markers were used for calculating the angles and lengths of the produced movements, and movement curvature was assessed using the path curvature index (Desmurget, Prablanc, Jordan & Jeannerod, 1999).

To only include trials in which the instructions were followed, the following hierarchical criteria were used to discard trials: (a) the stylus was moved after the third tone (i.e., 1000 ms after movement onset; late movement), (b) the stylus was lifted during movement (lift), (c) participants reversed the direction of drawing (reversal), (d) the angle of the movement deviated by more than 20° from the required angle or the length of the movement was shorter than half the motion length (trajectory failure). Trials were also discarded when the test stimulus was stopped at an angle that deviated by more than 5° from the stimulus motion angle or the button-press response occurred earlier than 200 ms after stimulus offset (concentration failure).

To obtain a measure of perceived motion direction (*PMD*), the angle of the stimulus motion (*SMA*) was subtracted from the angle at which the test stimulus (*TSA*) was stopped:

$$PMD = TSA - SMA.$$

That is, perceived motion direction was defined relative to the stimulus motion direction. These values were then averaged for each condition and participant. Given that the angles were coded relative to the upward direction (see Fig. 1), repulsion for rightward movements would lead to larger TSAs and thus larger (mainly positive) PMDs. Similarly, repulsion from leftward movements would lead to smaller TSAs and therefore smaller (mainly negative) PMDs. Consequently, the stronger the repulsion, the larger the difference between PMDs for rightward (PMD_r) and leftward (PMD_l) movements will be. To account for the fact that both movement directions contribute to this value, the CE was defined as the difference in PMDs divided by 2:

$$CE = \frac{PMD_r - PMD_l}{2}.$$

This is in line with earlier studies (Zwickel et al., 2010).

To detect an influence of movement condition on movement curvature and the CEs, one-way repeated-measures analyzes of

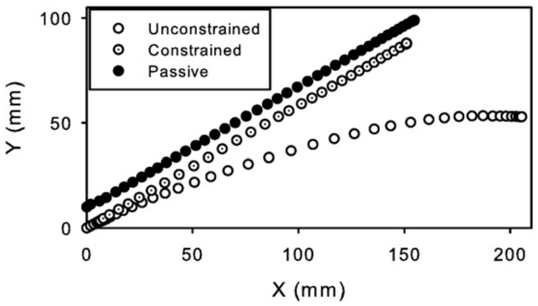

Fig. 2. Exemplary trajectories of one participant for movements to the right in the unconstrained, constrained, and passive movement conditions. From left to right every symbol marks the vertical and horizontal position of the stylus for consecutive 20 ms time slots. This means that areas with a dense symbol distribution mark phases of slow velocity and areas with spare symbol distributions phases of high velocity. To derive the positions for every 20 ms, the sampled vertical and horizontal positions were linearly interpolated. Because the constrained and passive trajectories virtually overlaid each other, for the purpose of illustration, the passive trajectory has been shifted vertically by 10 mm.

variance (ANOVAs) with the within-participant factor movement condition (unconstrained, constrained, and passive) were computed. Planned comparisons between the unconstrained and constrained and the constrained and passive conditions helped delineating the source of potential differences. Greenhouse–Geisser ε corrections were used when necessary.

1.2. Results

The mean percentages of excluded trials were 1.78%, 1.71%, 1.82%, 0.36%, and 4.40% for late movements, lifts, reversals, trajectory failures, and concentration failures. In total 10.07% of the trials were discarded.

Fig. 2 displays trajectory examples of one participant. As can be seen, the constrained and passive movements looked quite similar but the unconstrained movement was more curved than the other two. Indeed, the mean curvatures were 1.004, 1.001, and 1.002 for the unconstrained, constrained, and passive movement conditions, respectively. The ANOVA revealed a significant main effect of movement condition ($F(2, 46) = 54.19$, $MSE < 0.001$, $p < .01$). Planned comparisons showed that the constrained condition differed from the unconstrained ($F(1, 23) = 73.21$, $MSE < 0.001$, $p < .01$) and passive conditions ($F(2, 23) = 101.04$, $MSE < 0.001$, $p < 0.01$).[1]

As can be seen from the confidence intervals in Fig. 3, significant CEs were obtained in all but the passive condition (for completeness, the perceived motion directions as a function of movement condition and direction are provided in Table 1). The reliability of this pattern was corroborated by a significant main effect of movement condition ($F(2, 46) = 10.72$, $MSE = 0.54$, $p < .01$). Planned comparisons showed that the constrained condition differed from the passive condition ($F(1, 23) = 15.12$, $MSE = .89$, $p < .01$), but not from the unconstrained condition ($F(1, 23) < 1$).

1.3. Discussion

As expected, movement production interfered with motion perception: Perceived directions were repulsed by produced directions. Interestingly, the size of the CE did not differ between unconstrained and constrained movements even though the amount of movement curvature differed between the two conditions. This result supports the view that the precision of movement planning, which was presumably higher in the unconstrained condition, has no influence on the CE. Moreover, no CE was found when the hand was passively moved by a robot. This suggests that, in the absence of an intention to move, the integration of proprioceptive feedback of hand displacements is insufficient for the interference effect to arise.

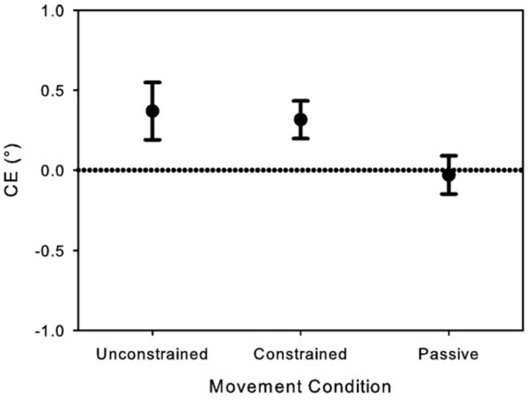

Fig. 3. Mean contrast effect (CE) as a function of movement condition (unconstrained, constrained, and passive) for Experiment 1. Whiskers indicate 95% confidence intervals.

2. Experiment 2

In Experiment 2, we asked whether the intention to produce a movement without actually moving the hand would be sufficient to produce a CE. Participants were always asked to produce constrained movements and the hand-held stylus was connected to a motor that could unexpectedly vary the amount of movement resistance or block the movement entirely. This allowed us to dissociate the intention to move from actual movement execution. That is, if intending to move is enough to cause interference, then a CE should be observed in the blocked condition as well. What is more, if the amount of force/effort required to move influences the strength of action–perception interference, then the larger the effort the larger CEs should be.

2.1. Method

The method was the same as Experiment 1 except where noted otherwise.

Table 1
Mean perceived motion direction (in degrees) as a function of movement direction (left and right) and movement condition (unconstrained, constrained, passive; weak, medium, strong, and blocked) for Experiments 1 and 2. Standard errors of the means are reported in parentheses.

Movement condition	Movement direction	
	Left	Right
Experiment 1		
Unconstrained	−0.40 (0.17)	0.34 (0.15)
Constrained	−0.33 (0.12)	0.30 (0.14)
Passive	0.06 (0.15)	−0.01 (0.13)
Experiment 2		
Weak	−0.23 (0.13)	0.20 (0.14)
Medium	−0.07 (0.12)	0.27 (0.15)
Strong	−0.05 (0.13)	0.28 (0.15)
Blocked	0.21 (0.14)	−0.17 (0.14)

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[1] One reviewer suggested to compare the size of the CEs between movements with high and low curvatures in the unconstrained condition to detect a potential effect of the precision of planning. When a median split was performed on movement curvature, the mean CE was numerically larger for movements with low curvature (0.45°) than high curvature (0.29°), but the difference did not reach significance ($t(23) = 1.78$, $p < .10$). Moreover, it's unclear to what extent movement curvature actually provides a valid measure of the *precision* of movement planning.

2.1.1. Participants, stimuli, movements, and apparatus

Twenty-four right-handed individuals (mean age = 24 years; 6 females) took part in this experiment. This time, the stimulus motion traversed a distance of 19 cm from its horizontally centered starting position, 7 cm below the horizontal midline of the monitor. More critically, depending on the movement condition, the motor resisted the movement of the stylus to varying degrees. In the weak, medium, and strong conditions about 0.33, 0.80, and 1.00 N of force were required to move, respectively. In the blocked condition, movements could only be performed if more than 20 N were applied. The hand-held stylus was connected to a board that could be moved along a 19 cm rail (see Fig. 4).

2.1.2. Design

Repeated measures were obtained within participants for a factorial combination of movement direction (left and right) and movement condition (weak, medium, strong, and blocked). Each movement direction occurred in nine consecutive blocks of 16 trials each. The order of the movement directions was counterbalanced across participants. Movement conditions changed from trial to trial in a pseudo-random order that guaranteed an equal occurrence of each movement condition. Every participant performed 288 trials in total.

2.1.3. Procedure

Participants wore headphones to avoid any acoustic cues from the motor that could have provided information about the upcoming movement condition. To further mask any acoustic cues, a 440 Hz tone was played for 100 ms after participants had moved inside the start circle, as this was when the degree of motor resistance was set. The rest of the tone sequence resembled that of Experiment 1. Prior to the first block of a given movement direction, participants practiced the required movement direction. To avoid displacing the entire apparatus, participants were instructed to stop increasing their force when they detected that their movement was being completely blocked. If participants did not complete their movement or moved in the blocked condition (blocking was released after the end of recording), an error message to that effect was shown. The next trial started after a 1000 ms interval.

2.1.4. Data analysis

The data were analyzed in the same way as in Experiment 1 except that trials were also excluded when participants moved in the blocked condition (blocked failure). Moreover, since participants always moved along a rail, movement curvature was not considered.

To detect an influence of movement condition on the CE, a one-way repeated-measures ANOVA was computed with movement condition (weak, medium, strong, and blocked) as the within-participant factor. Planned comparisons between the weak and medium, between the medium and strong, and between the strong and blocked conditions were used to investigate potential differences between the conditions.

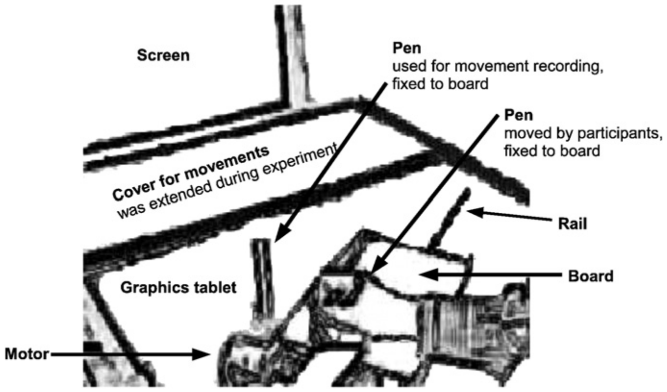

Fig. 4. Setup of Experiment 2. Participants moved a stylus that was connected to a board that moved along a rail. The board was connected to another stylus that was used to allow recording of the movement on the graphics tablet. During the experiment participants' view of their hands was prevented by a board.

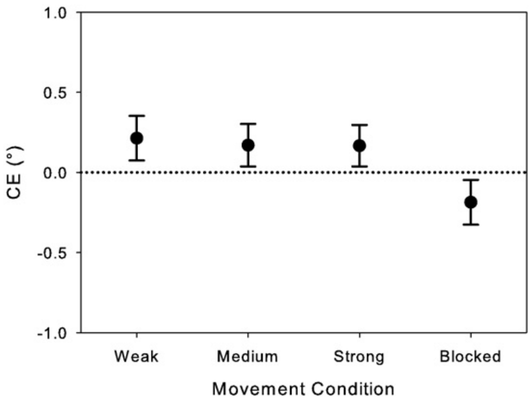

Fig. 5. Mean contrast effect (CE) as a function of movement condition (weak, medium, strong, and blocked) for Experiment 2. Whiskers indicate 95% confidence intervals.

2.2. Results

The mean percentages of excluded trials were 1.09%, 1.87%, 0.23%, 0.28%, 3.05%, for blocked, late movements, reversals, trajectory, and concentration failures. In total 6.52% of the trials were discarded.

Fig. 5 presents the mean CEs as a function of movement condition (for the perceived motion direction data, see Table 1). As indicated by the confidence intervals, all movement conditions, except for the blocked condition, led to significant CEs. In the blocked condition, a significant attraction (assimilation) effect was observed. Consistent with this pattern, the ANOVA yielded a significant main effect of condition ($F(3,\ 69) = 14.79$, $MSE = 0.36$, $p < .001$). Follow-up tests revealed a significant difference between the blocked and strong conditions ($F(1,\ 23) = 21.70$, $MSE = .61$, $p < .001$), but no differences between the strong and medium ($F(1,\ 23) = .51$, $MSE = .12$, $p > .10$) or medium and weak ($F(1,\ 23) = .65$, $MSE = .29$, $p > .10$) conditions.

2.3. Discussion

A significant CE was obtained for the weak, medium, and strong movement conditions. However, when participants were prevented from moving (i.e., in the blocked condition), a significant attraction (assimilation) effect was observed. This suggests that intending to move without movement execution is not sufficient to produce a CE. Nevertheless, it is interesting to note the apparent similarity of the latter finding to that obtained by Haggard, Poonian and Walsh (2009) with voluntarily inhibited actions. In their paradigm, participants were asked to spontaneously inhibit their intention to act in some trials. Inhibiting the intention to move led to a reversal in the direction of influence of action on the perception of a subsequent stimulus. In the blocked condition of the current study, one could assume that, after detecting the amount of resistance posed by the robot, participants inhibited their movement by activating an intention to move in the opposite direction. If all this could occur within the 500 ms of stimulus presentation, then the change in movement intention could have potentially lead to a reversal of the effect of action on perception.

An alternative account is that intending to move leads, by default, to an assimilation between what is produced and perceived due to an intrusion of features, and that contrast actually arises during movement execution when action and perception events are shielded from each other. Evidence for this idea comes from a recent study by Grosjean, Zwickel and Prinz (2009) that focused on the influence of perception on concurrent action. Using a similar paradigm to the one employed here, they observed a bi-phasic pattern of specific interference: Hand movements went in the direction of the stimulus motion for the first 100–200 ms, before deviating away from the stimulus motion after about 250 ms. One could speculate that the intention to move is what caused assimilation and that this effect then reversed (or was masked) over the course of movement execution. If this is the case, then preventing individuals to move would only allow the (initial) intention-based assimilation effect to be observed.

Although CEs were found for all the conditions in which participants could move (i.e., weak, medium and strong), the amount of effort did not modulate the size of the CEs. This stands in contrast to the study of Witt et al. (2004), in which perceived target distances were found to increase with the amount of recent motor effort. However, given the large amount of methodological differences between the latter and the current study, it's difficult to establish what might have led to the (apparent) discrepancy in findings without further experimentation.

Finally, as pointed out by a reviewer, the analyzes performed until now ignore potential effects of movement direction. Although left–right asymmetries were not the focus of this study, we calculated an additional repeated-measures ANOVA on the perceived motion directions (see Table 1) with the factors movement direction (left and right) and movement condition (weak, medium, and strong). No main effect of movement condition ($F(2, 46) = 2.73$, $MSE = .12$, $p < .10$), nor an interaction between movement condition and movement direction was found ($F < 1$). This points to the absence of any asymmetries in the effect of leftward and rightward movements on perception. However, a significant effect of direction was found ($F(1, 23) = 9.86$, $MSE = 0.49$, $p < .01$), reflecting a significant CE.

3. General discussion

Two experiments investigated which part(s) of an action interfere(s) with the perception of a concurrently presented stimulus motion. In Experiment 1, participants produced hand movements without any guidance (unconstrained), along a slit (constrained), or had their hands transported by a robot (passive). In line with previous findings (Zwickel et al., 2008, 2010), perceived motion directions were repulsed by produced directions in the unconstrained and constrained conditions, however no difference in the size of the CEs between the two conditions was found. This suggests that the precision of movement planning does not play a critical role in such tasks. Instead, it supports the conclusions of Zwickel et al. (2010) that specific interference effects stem from the involvement of coarse directional categories, rather than detailed directional representations. According to this proposal, feature overlap between categories that are activated by the movement/motion, such as "right-up"/"upwards", is what causes the CEs to arise (see Hommel, Müsseler, Aschersleben & Prinz, 2001; Müsseler & Hommel, 1997).

No repulsion effect was found in the passive condition. This supports the notion that the proprioception of hand displacements is insufficient to produce the CE. This result is also consistent with the findings of Müsseler, Wühr and Prinz (2000), who investigated how the preparation of discrete manual responses (e.g., button presses) interfere with the perception of briefly presented feature-overlapping stimuli (e.g., arrow heads). Interestingly, they only found an interference effect when the side of the intended (instructed) action was consistent with the evoked motor activity. In their task, participants had two of their fingers rest on contact switches. In one condition they had to maintain the contact on one side, which required a release response (and motor activity) on the other side. Therefore, in this condition, intended response side and side of motor activity differed. In another condition, participants were to release one side, which required them to maintain contact with the other side. Thus, the intended side and the side of motor activity were the same in this condition. Only in the latter condition was an interference effect found. This could explain why we did not find interference in the passive condition, as there was no motor activity that corresponded to the direction of movement.

Experiment 2 manipulated the amount of force/effort needed to move as well as whether participants were able to move at all (blocked condition). As long as participants were able to execute their intended movements, reliable CEs were observed. However, the amount of effort required did not modulate the size of the CEs. This finding is reminiscent of observations from action–action interaction paradigms, in which directional interference in bimanual movements have been found to be independent of force manipulations (Swinnen, Dounskaia, Levin & Duysens, 2001).

In the blocked condition, an attraction (assimilation) effect, rather than a CE, was actually found. The absence of a CE in this condition is potentially at odds with other phenomena, such as action–effect blindness, which was already considered above (Müsseler & Hommel, 1997; Wühr and Müsseler, 2001). The latter form of motor-induced perceptual impairment is already present during the planning of direction-compatible button presses. This difference in results might be caused by the continuous stimulus presentation in the current paradigm. According to this view, planning is only sufficient to hamper perception when the perceptual event is short-lived and no continuous perceptual updating occurs. An alternative explanation would be that the present paradigm reduced the need to plan the movements because of the absence of speed stress and the fact that the same movement was always repeated within a block.

Our proposal that assimilation, as observed in the blocked condition, is the default form of interference is supported by observations of Grosjean et al. (2009) who found that hand movements initially veered toward concurrent stimulus motions and only later started to deviate in the opposite direction. This pattern of early attraction followed by repulsion has also been found by Whitney, Westwood and Goodale (2003) and Gomi, Abekawa and Nishida (2006). Because the current movements were typically longer than 500 ms, a CE would have also been expected for the produced movements in the current study and was indeed found in a similar paradigm (Zwickel et al., 2010). In our view, the subsequent CE depends on the presence of two functionally unrelated tasks. One might speculate that only when one's own action effects can be perceived does competition between features of the produced and observed movements arise, thereby leading to a contrast effect. It is interesting to note that in another paradigm that involved motion perception, facilitation of perceived motions that were congruent with planned actions was observed (Lindemann & Bekkering, 2009). In Lindemann and Bekkering (2009) participants were asked to plan a grasp and rotate of an X-shaped object. A visual go signal was detected faster when it was congruent with the planned action.

In sum, the current experiments demonstrate that specific interference effects only arise in concurrent perception–action tasks when people both intend (Experiment 1) and are actually allowed to move (Experiment 2).

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