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Markus Janczyk · Roland Pfister · Wilfried Kunde

Abstract Human–Computer Interactions pose special demands on the motor system, especially regarding the virtual tool transformations underlying typical mouse movements. We investigated whether such virtual tool-transformed movements are similarly resistant to irrelevant variation of a target object as skilled natural movements are. Results show that such irrelevant information deteriorates performance in perceptual tasks, whereas movement parameters remain unaffected, suggesting that the control of virtual tools draws on the same mechanisms as natural actions do. The results are discussed in terms of their practical utility and recent findings investigating unskilled and transformed movements in the framework of the action/perception model and the integration of tools into the body schema.

Introduction

Tools have played an important role in human phylogeny and populate wide areas of everyday life, but a radical change in tool use has occurred only recently: While our stone-age ancestors likely were immersed in using flint stones, nowadays the computer mouse is one of the most prevalent tools in human life. Such mouse movements entail two different components: Identifying what is to be acted on (e.g., a specific target icon) and performing

the particular action toward this goal (e.g., moving the cursor toward the icon). This movement is subject to a rather abstract transformation from hand to mouse movement, which distinguishes the computer mouse from other tools such as hammers or scissors with obvious mechanical transformations. Arguably, this abstract transformation poses special demands on the mouse user.

In what follows, we first describe how tools can (or cannot) become integrated into the body schema of an agent and continue by discussing how susceptible mouse movements are to irrelevant information. We then focus on the question whether mouse movements show hand-like characteristics in that they are not susceptible to stimulus-inherent, but task-irrelevant distraction.

Can external tools become represented as body parts?

Clearly, everything inside the skin surrounding a human body can be experienced as part of the body. Yet, this may also be true for parts external to the body. For example, in the rubber-hand illusion (Botvinick and Cohen 1998), participants experience a rubber hand to belong to them, driven by synchronized stimulation of their real and the rubber hand. Similar illusions have been reported for virtual reality settings involving the arm (Slater et al. 2008) and even the whole body (Slater et al. 2010). In contrast, such illusions diminish when using abstract avatars such as a simple arrow (Yuan and Steed 2010). Thus, rather abstract body extensions such as tools may not give rise to own-body illusions and thus behave differently than external body-like parts.

On the other hand, early neuroscientific work has suggested that mechanical tools can become part of the body schema even without extensive practice (Iriki et al. 1996), and tools can also influence perception in peri-personal

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space (e.g., Farnè and Làdavas 2000; Witt et al. 2005). Thus, at least to some degree, mechanical tools appear to be integrated into the body schema and eventually behave like body parts. However, in light of the study by Yuan and Steed (2010), it is unclear whether this is as well true without obvious mechanical transformations.

As mentioned above, typical mouse movements entail two different components: identifying the target and performing the movement. According to the well-known action/perception model (Goodale and Milner 1992; Goodale 2008), these tasks map on different neural substrates: The ventral visual stream from V1 to inferior temporal areas processes visual information for conscious perception. In contrast, the dorsal visual stream from V1 to posterior parietal areas is responsible for planning and controlling visually guided movements. Several studies suggested, however, that this is only true for natural, skilled movements of the right hand (Gonzalez et al. 2006, 2008). These studies relied on the idea that perceptual, but not action tasks, suffer from visual illusions (Aglioti et al. 1995). While being taken as major evidence for the action/perceptual model, this idea has also caused an intense debate about methodological and statistical drawbacks (e.g., Franz and Gegenfurtner 2008). Yet, Gonzalez et al. reported that left-handed and awkward, unskilled grasping movements were susceptible to visual illusions, suggesting that these movements relied on perceptual information and did not behave like a skilled, right-handed movement. Conceivably, tools even further deviate from natural movements, and thus, these studies cast doubt on the idea that tools may eventually behave like natural body parts, in this case, the right hand. This should apply especially to rather abstract tool transformations such as computer-mouse movements.

Here, we explore these possibilities by focusing on a particular characteristic of movements: their susceptibility to interference from irrelevant stimulation.

Influences of irrelevant information on mouse movements

Human–Computer Interaction (HCI) literally means to interact with the computer, and most often this is done by manipulating a computer mouse. Studies on modern PC-based work places suggest an average of 1,000 mouse clicks per hour (Taylor 2007) with many clicks preceded by a move toward a target region. Clearly, it is of practical importance to know how irrelevant stimulation affects this type of motor interaction.

In fact, irrelevant information is highly prevalent for both the target identification and the moving aspect of HCI. Windows pop up to praise new software updates, and internet pages often contain attention-grabbing advertisements that compete with actual content (e.g., Evans 2009). Although certain sources of distraction help to improve usability experience (Zhang and von Dran 2000), irrelevant information seriously affects performance—even if the agent tries to ignore the corresponding stimuli (e.g., McDougall et al. 2000).

Furthermore, research has shown mouse trajectories to be clearly susceptible to ambiguous information. For example, in a gender-classification task, participants were more attracted by the opposite gender label in case of gender-atypical than gender-typical faces. This effect was evident in the mouse movements, although in both conditions, the cognitive operations finally converged into the same response, i.e., mouse clicking the correct gender label (Freeman et al. 2008; see also Freeman and Ambady 2011). Similar effects were observed when participants were confronted with to-be-ignored information, e.g., when tracking a road while visual distractors appeared at random locations (Vilchez and Tornay 2012).

In these studies, irrelevant information was presented at a location different from the cursor's actual goal. Here, we focused on whether also irrelevant information inherent in the stimulus to-be-acted on affects mouse trajectories. Thus, the present experiments extend previous research by examining the impact of irrelevant information contained in task-relevant stimuli. Practically, such situations occur, e.g., when potential target items in a website change their color to attract the user's attention. Notably, natural, right-handed grasping movements were shown to be unaffected by such irrelevant information, whereas mere perceptual judgments on the stimulus were negatively affected (Ganel and Goodale 2003); the case of mouse movements has not been investigated yet.

The present experiments

A method to investigate the impact of irrelevant information of task-relevant stimuli is Garner's speeded classification task (Garner 1974, 1978), where participants classify stimuli according to a task-relevant dimension in two block types. In *baseline blocks*, an additional but task-irrelevant dimension of the stimuli is held constant, whereas in *filtering blocks,* this second dimension varies. Garner-Interference shows up as performance differences between these block types: If the two dimensions cannot be perceived separately, i.e., if they are spontaneously combined into a composite percept, performance is worse in filtering compared to baseline blocks. In other words, in such cases, the irrelevant dimension cannot efficiently be filtered out.

We transferred the study design as previously used with manual actions (Ganel and Goodale 2003; Janczyk and Kunde 2010; Kunde et al. 2007; see also Janczyk and Kunde 2012) to a computer setting involving a virtual tool transformation. Stimuli were virtual two-dimensional rectangles that varied on their width and their height dimension. Experiment

1 investigated two different scenarios with a perceptual and an action task performed by different samples. In the perceptual task, participants indicated stimulus height by a simple key press to establish that the computerized version of the stimuli can in principle produce Garner-Interference. In the action task, the very same stimuli were then targets of mouse movements and participants performed a mouse click within an invisible target area that was vertically centered and stretched the whole stimulus horizontally ("horizontal midline"; see Fig. 2 for an illustration). In Experiment 2, we combined perceptual and action aspects into a single task, to gather data from both aspects from the same participants. To avoid misunderstandings, we like to point out two things here. First, the upper part of the stimuli was presented at fixed y-coordinates. Therefore, the exact position of the target area varied with stimulus height and prevented participants from knowing the exact target coordinates in advance. That is, whereas in the Ganel and Goodale (2003) study, the task was to grasp across the relevant dimension (width); here the task was to split the relevant dimension (height) into two equal parts. Secondly, the target area was not highlighted or marked otherwise, thus always to be inferred from stimulus height.

In a nutshell, perceptual judgments should suffer from irrelevant stimulus dimension variability and therefore show Garner-Interference (cf. Ganel and Goodale 2003). The interesting question relates to the action task: Previous research on the representation of virtual body parts (Yuan and Steed 2010) and considerations based on the action/perception model (Gonzalez et al. 2006, 2008) do not suggest mouse movements adopt characteristics of natural right-handed movements; therefore, similar Garner-Interference should result here. However, as external parts such as mechanical tools were shown to be included into the body schema (Iriki et al. 1996), even mouse movements may prove to be resistant to irrelevant variation and thus exhibit no Garner-Interference.

Finally, for natural grasping and pointing movements, interference effects were sometimes only evident in kinematic measures (e.g., Hesse et al. 2008). Accordingly, we also present analyses of the continuous trajectories (for reviews on this method, see Freeman et al. 2011; Song and Nakayama 2009). For example, if the additional variation in the filtering blocks introduces uncertainty, this may become visible as larger variances of end positions or larger curvatures. Additionally, if a controlled approach starts earlier in these blocks, the time to maximum speed should also be reached earlier.

Experiment 1

Experiment 1 implemented computerized versions of a perceptual and an action tasks in two different scenarios. In Experiment 1a, the target stimulus appeared in a central position. In the action task, the starting position was variable to mimic approaching a relatively constant target area (e.g., a menu button) from different locations. As a consequence, however, the stimuli did not vary along the x-axis in baseline blocks, whereas they did in filtering blocks. Thus, in Experiment 1b, we presented stimuli in random positions on each trial of the perceptual task and varied the stimulus position in the action task as well, but participants now departed from a constant starting position.

Methods

Participants

A total of ninety-six undergraduates participated, with 48 performing the perceptual tasks ($n = 24$ each; Exp. 1a: 19 female, mean age = 23.6 years; Exp. 1b: 22 female, mean age = 22.7 years), and the other 48 performing the action tasks ($n = 24$ each; Exp. 1a: 15 female, mean age = 26.2 years; Exp. 1b: 18 female, mean age = 25.3 years). All participants were naïve regarding the hypotheses and reported normal or corrected-to-normal vision.

Apparatus and stimuli

Target stimuli in both tasks were four boxes, resulting from the orthogonal combinations of a small and a large width (6.3 vs. 7.5 cm) as well as a small and a large height (3.0 vs. 3.6 cm). Irrespective of the actual box size, the height of the target area in the action tasks was 0.7 cm, centered on the horizontal midline. Stimuli were presented in white against a black background on a 17″ monitor. Responses in the perceptual tasks were collected via two custom-made buttons. In the action tasks, participants operated a standard computer-mouse and physical mouse movements were translated into virtual cursor movements without velocity-dependent gain; the cursor was displayed as a cross of 0.8 cm × 0.8 cm.

In Experiment 1a, the target stimuli were displayed in the center of the screen. Start positions in each trial were circles of 1 cm diameter appearing in the upper or lower half of the screen (5.8 cm away from the center of the screen). To ensure that participants in the action task processed the box height and could not learn an optimal target point to produce a correct response in each trial we varied the exact vertical position of the box randomly from 0 to 1.1 cm toward the bottom of the screen (using a uniform distribution).

In the perceptual task of Experiment 1b, the stimulus appeared at random coordinates within an invisible square ($800 \times 600 \text{ px}^2$) centered at fixation. In the respective action task, only the lower start position was used. Target stimuli appeared at one of four possible locations, arranged on an invisible circle around the start position (in steps of 30°, starting at 45°). The top border of each stimulus box was

aligned to the circle described above (i.e., the distance to the home button was approximately 10.8 cm for all locations).

Procedure

In the perceptual tasks, each trial began with a fixation cross (500 ms), followed by the target stimulus until a response was given or 4,000 ms elapsed without a response. Erroneous responses triggered feedback messages (1,500 ms). The next trial started after 1,000 ms. Participants were instructed to classify stimuli according to their height by pressing a response key with their right index- or middle-finger.

To start trials in the action tasks, participants had to move the cursor in the home area. A warning click (3,000 Hz, 50 ms) was triggered after a dwell time of 500 ms and the target appeared after additional 500 ms. Participants were instructed to click anywhere on the horizontal midline of the box as quickly as possible by making a single, smooth movement. They were also informed that only relatively accurate clicks would count as correct responses but they were not shown the exact target area. Correct responses made the box color fade to blue (for 500 ms) and the screen went black afterward (for 1,000 ms). Responses prior to target onset and wrong responses stopped the trial immediately and were followed by an error message (1,000 ms).

Participants worked through 24 (perceptual) or 32 (action) practice trials which included all four target stimuli and, for the action task, both start positions (Exp. 1a) or all stimulus positions (Exp. 1b). The four subsequent experimental blocks comprised 72 trials in the perceptual tasks. In the action task, 64 trials were used in Experiment 1a; in Experiment 1b we slightly increased the trial number to 80 per block to counteract the higher number of trial types. Target stimuli and—in the action task—start positions (Exp. 1a) or stimulus positions (Exp. 1b) were randomly intermixed and appeared equally often within blocks. The four blocks comprised two baseline blocks (using only stimuli of the same width) and two filtering blocks (using all four stimuli) with their order counterbalanced across participants, as was S–R-mapping in the perceptual task. Prior to each block, participants were informed about the possible target stimuli and encouraged to carefully inspect their width and height dimensions before starting the block.

Design and analyses

Response times (RT) in the perceptual tasks were analyzed with an Analysis of Variance (ANOVA) with block type (baseline vs. filtering) as a repeated measure.[1] In the action tasks, movement onset was defined as the point when the cursor had just left the starting position and this event was logged as RT. From this point onward, we sampled cursor trajectories (*x*- and *y*-coordinates) at 200 Hz. Movement time (MT) was computed as the time between movement onset and the final mouse click.

To complement RT and MT analyses, we calculated additional measures from the mouse trajectories. Trajectory data of each trial was normalized to 101 time-steps via linear interpolation and the following parameters were extracted: final *x*-coordinate (x_{final}, in px),[2] time to maximum speed (T_{max}, in %), and curvature (CURV). Curvature was computed as the ratio of actual trajectory length and optimal trajectory length as defined by a straight line from start to end point. For RTs, MTs, T_{max}, and CURV we computed means of the individuals' condition means and for x_{final} we computed the mean of the individuals' condition variance[3] for each combination of block type (baseline vs. filtering) and start position (Exp. 1a: top vs. bottom) or stimulus position (Exp. 1b: 1–4). These data were then subjected to separate 2 × 2 or 2 × 4 ANOVAs with both factors as repeated measures. Greenhouse-Geisser corrections were applied where necessary, although we report unadjusted degrees of freedom for clarity. To substantiate differences in Garner-Interference for the perceptual and the action task, we ran additional mixed ANOVAs on RTs and error percentages including block type (baseline vs. filtering) as a repeated measure and task (perceptual vs. action) as a between-subjects factor.

Only correct trials were considered for RT, MT, and trajectory analyses. Further, we identified outliers as those RTs deviating from an individual's mean in the respective design cell by more than 3 SDs (perceptual tasks: Exp. 1a: 1.9 %, Exp. 1b: 2.1 %; action tasks: Exp. 1a: 1.5 %, Exp. 1b: 1.5 %). The same criterion was then applied to MTs, leading to an exclusion of another 1.1 and 0.7 % of trials for Experiment 1a and 1b, respectively. For error analyses, we excluded anticipations (i.e., mouse movements prior to target onset; Exp. 1a: 2.9 %; Exp. 1b: 2.2 %). Hence, errors indicate that participants clicked on the target stimulus box, but failed to hit the target area.

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[1] We preferred ANOVA over paired-samples *t*-tests to provide better comparability of the resulting effects sizes with subsequent analyses involving multiple factors.

[2] The final *y*-coordinate was tightly restricted by the target zone participants were to click on, and we thus did not analyze this dependent measure.

[3] We also computed means of x_{final} and there were significant effects on this variable in Experiments 1b and 2. The corresponding inferential statistics can be found in Table 2; these effects, however, are trivial, since the box coordinates varied on the *x*-axis in these experiments.

Results

Experiment 1a

Perceptual task RTs were longer in filtering than in baseline blocks (Fig. 1, left panel), $F(1,23) = 21.43$, $p < .001$, $\eta_p^2 = .48$, and more errors were made in filtering blocks (Table 1), $F(1,23) = 8.46$, $p = .008$, $\eta_p^2 = .27$.

Action task: RTs, MTs, and error percentages RTs and MTs in the action task are visualized in Fig. 1 (left panel), collapsed across the factor start position. Descriptively, RTs were slightly faster with the lower starting position, $F(1,23) = 2.42$, $p = .133$, $\eta_p^2 = .10$. Importantly, neither the main effect of block type, $F(1,23) = 0.04$, $p = .845$, $\eta_p^2 < .01$, nor the interaction of block type and start position was significant, $F(1,23) = 0.62$, $p = .438$, $\eta_p^2 = .03$. Similarly, MTs were longer with the upper start position, $F(1,23) = 42.29$, $p < .001$, $\eta_p^2 = .65$, but no other effect approached significance, block type: $F(1,23) = 0.07$, $p = .794$, $\eta_p^2 < .01$, interaction: $F(1,23) = 0.71$, $p = .407$, $\eta_p^2 = .03$. Error percentages are summarized in Table 1, and no effect was significant, all $Fs \leq 2.41$, all $ps \geq .134$.

Action task: trajectory data Trajectories are visualized in Fig. 2 (upper panel). Means of the dependent variables are illustrated in Fig. 3 (left column). In line with RT and MT analyses, the trajectory data revealed no significant effects of block type and no significant interaction involving this factor (see Table 2 for details).

Between-task analyses The mixed ANOVA on RTs showed the critical interaction of block type and task to be significant, $F(1,46) = 19.74$, $p < .001$, $\eta_p^2 = .30$, with larger Garner-Interference in the perceptual than in the action task. The same was true for percentage errors, $F(1,46) = 5.96$, $p = .019$, $\eta_p^2 = .11$.

Experiment 1b

Perceptual task RTs were longer in filtering than in baseline blocks (Fig. 1, right panel), $F(1,23) = 6.52$, $p = .018$, $\eta_p^2 = .22$, and more errors occurred in filtering blocks (Table 1), $F(1,23) = 9.13$, $p = .006$, $\eta_p^2 = .28$.

Action task: RTs, MTs, and error percentages RTs and MTs in the action task are visualized in Fig. 1 (right panel), collapsed across the factor stimulus position, and no effect was significant for RTs, block type: $F(1,23) < 0.01$, $p = .995$, $\eta_p^2 < .01$, stimulus position: $F(3,69) = 1.50$, $p = .230$, $\eta_p^2 = .06$, interaction: $F(3,69) = 0.15$, $p = .883$, $\eta_p^2 = .01$. The same was true for MTs, block type: $F(1,23) = 0.10$, $p = .759$, $\eta_p^2 < .01$, stimulus position: $F(3,69) = 0.33$, $p = .702$, $\eta_p^2 = .01$, interaction: $F(3,69) = 2.65$, $p = .086$, $\eta_p^2 = .10$. Error percentages are summarized in Table 1, and no effect was significant, all $Fs \leq 1.69$, all $ps \geq .207$.
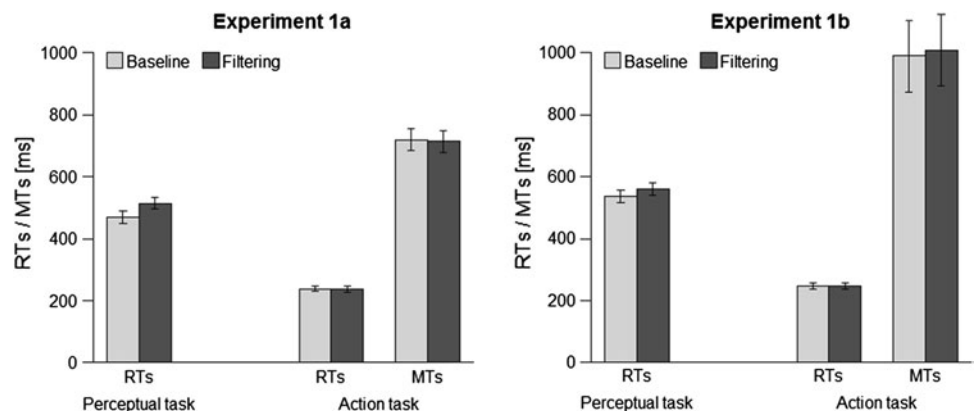
Action task: trajectory data Trajectories are visualized in Fig. 2 (middle panel), and means of the dependent variables are illustrated in Fig. 3 (middle column). There was only a significant effect of stimulus position on CURV, reflecting larger deviations from the ideal trajectory when moving to the left- or right-most stimulus positions compared to the two more centrally located stimuli (see Table 2 for details). Most importantly, however, block type neither produced a main effect on any dependent variable nor entered into any interactions.

Between-task analyses Again, the critical interaction of block type and task in the mixed ANOVA was significant for RTs, $F(1,46) = 5.07$, $p = .029$, $\eta_p^2 = .10$, with larger Garner-Interference in the perceptual than in the action task. For error percentages, the interaction was not significant, $F(1,46) < 1$.

Discussion

The results are straightforward. Garner-Interference emerged for the perceptual tasks, with worse performance in filtering compared to baseline blocks. By contrast, no signs of Garner-Interference were observed in the action tasks. This was true for classical measures such as RTs, MTs, and error percentages, and for measures derived from the trajectory data.

Fig. 1 Mean reaction times (RTs) and movement times (MTs) of Experiment 1 as a function of task (perceptual vs. action) and block type (baseline vs. filtering). Error bars are 95 % within-subject confidence intervals (Pfister and Janczyk 2013)

Table 1 Error percentages from Experiments 1 and 2 as a function of block type (baseline vs. filtering) and start or stimulus position
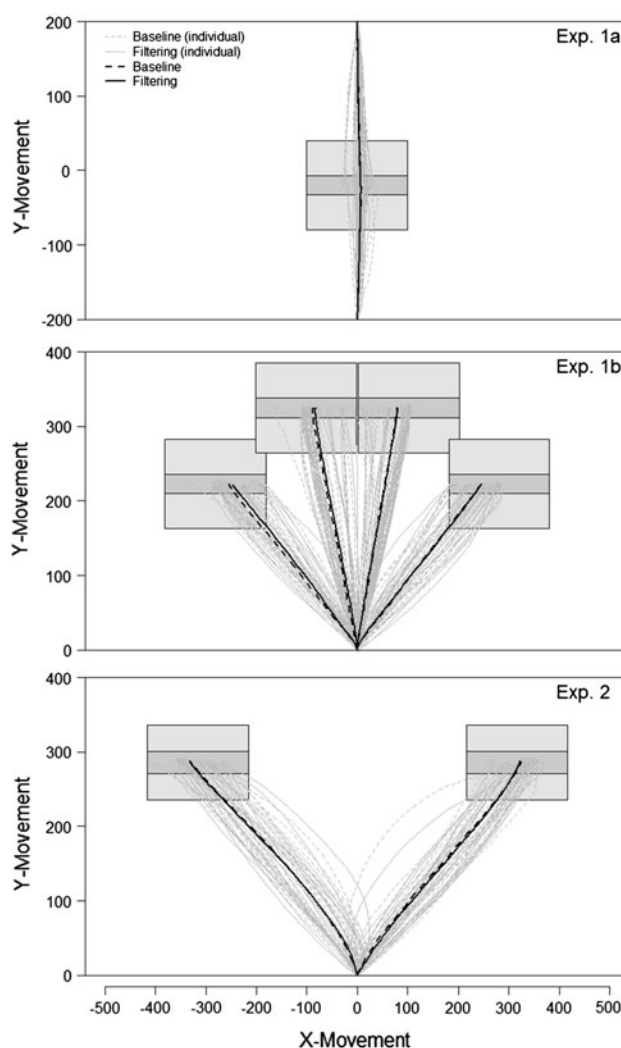
	Baseline	Filtering
Experiment 1a		
Perceptual task	5.8	8.8
Action task		
Upper start position	3.3	3.8
Lower start position	3.6	2.9
Experiment 1b		
Perceptual task	5.8	8.8
Action task		
Stimulus position 1	2.4	1.9
Stimulus position 2	1.8	2.4
Stimulus position 3	1.5	3.1
Stimulus position 4	1.9	2.7
Experiment 2		
Perceptual component		
Left stimulus position	0.1	0.6
Right stimulus position	<0.1	0.1
Action component		
Left stimulus position	3.1	4.2
Right stimulus position	3.3	3.7

Fig. 2 Illustration of trajectories as a function of block type (baseline vs. filtering). *Gray lines* represent individual trajectories, and *black lines* are trajectories averaged across participants. For illustrative purposes, the possible target stimuli are shown, where clicks in the *dark gray* area centered around the "horizontal midline" would count as correct

This finding might of course give rise to concerns regarding the power of the conducted analyses. A reasonable assumption seems to be that the interference effect in the action tasks were of similar size as in the perceptual task of Experiment 1b (that controlled for x-axis variation; $d = 0.74$). The power to detect an effect of this size amounted to $1-\beta > .93$ (given $n = 24$, and $\alpha = .05$). Thus, the achieved power was reasonably high to assume nil effects in the action task.

In sum, while perceptual decisions suffer from Garner-Interference, mouse movements toward the very same stimuli do not. Experiment 2 corroborates this conclusion by combining perceptual and action components into a single task.

Experiment 2

In Experiment 2, we gathered perceptual and action data from the same participants within a task that required a perceptual decision followed by a mouse movement toward the correct target. Participants were confronted with one target to the left and one target to the right in each trial. They had to identify the higher stimulus and perform the same action task as in Experiment 1 on it. Note that there was no actual response such as a key press following identification of the higher stimulus, but participants were instructed to immediately perform the mouse movement toward the target sti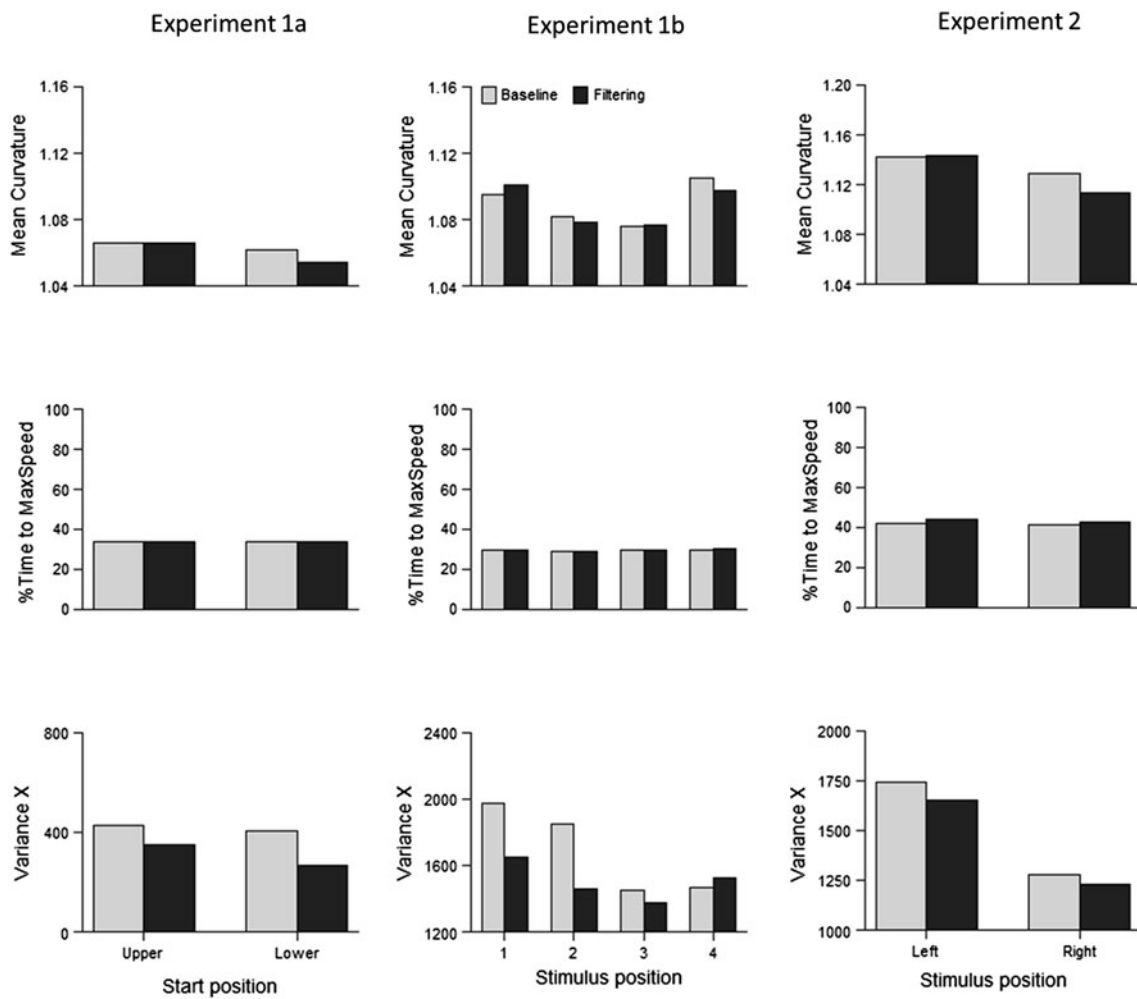mulus once identified. We expected to observe Garner-Interference in RTs (operationalizing the perceptual component of the task), but not in MTs and trajectory measures (operationalizing the action component of the task).

Method

Participants

Twenty-four new undergraduate students participated for monetary compensation (18 female, mean age = 22.1 years). They fulfilled the same criteria as in Experiment 1.

Fig. 3 Mean values of trajectory parameters as a function of block type (baseline vs. filtering) and start position (Exp. 1a) or block type and stimulus position (Exp. 1b and 2), respectively. For Experiment 1b, Positions 1–4 refer to positions from *left-most* to *right-most*, respectively

Table 2 Detailed statistics for trajectory analyses

Dependent variable	Factor	Experiment 1a			Experiment 1b			Experiment 2		
		F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Mean curvature	Block type	0.40	.532	.02	0.01	.917	<.01	1.04	.318	.04
	Position	1.79	.194	.07	8.43	<.001	.27	2.99	.097	.12
	Block type × position	1.63	.215	.07	0.85	.470	.04	1.64	.213	.07
T_{Max}	Block type	<0.01	.978	<.01	0.14	.709	.01	9.95	.004	.30
	Position	0.02	.898	<.01	1.90	.159	.08	8.86	.007	.28
	Block type × position	0.77	.389	.03	0.92	.436	.04	5.77	.025	.22
Mean X	Block type	0.49	.492	.02	2.01	.170	.08	1.78	.195	.07
	Position	0.61	.442	.03	896.38	<.001	.97	3,391.66	<.001	.99
	Block type × position	0.12	.732	.01	0.52	.496	.02	0.19	.668	.01
Variance X	Block type	1.81	.192	.07	0.97	.335	.04	0.77	.389	.03
	Position	0.20	.658	.01	1.43	.250	.06	0.03	.871	<.01
	Block type × position	<0.01	.946	<.01	2.12	.131	.08	2.76	.110	.11

Note that "Position" refers to start position in Experiment 1a, and to stimulus position in Experiments 1b and 2. Degrees of freedom (dfs) were 1 and 23 in most analyses, except those involving the factor position in Experiment 1b, where *df*s were 3 and 69, respectively

Apparatus, stimuli, and procedure

Experiment 2 was similar to Experiment 1b, but only the two outer target positions were used (and moved to more peripheral coordinates). On each trial, a stimulus appeared in each position. While the width of both stimuli was identical on each trial, both differed regarding their height. The higher stimulus appeared equally often at both positions in random order. Participants were to identify the higher stimulus and perform a mouse click on its horizontal midline as in Experiment 1.
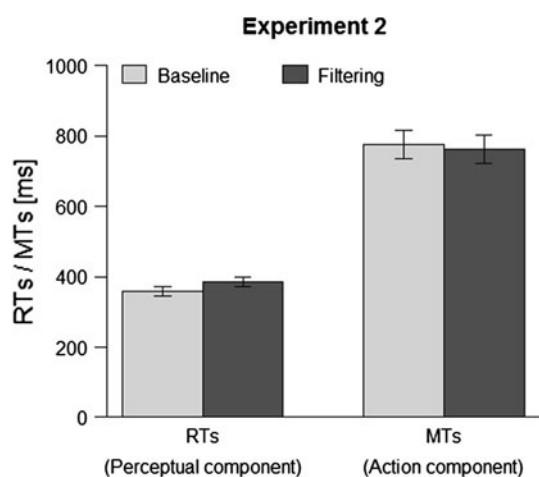
Design and analyses

Analyses were similar to those in Experiment 1b, but stimulus position had only two levels (left vs. right). Data were submitted to a 2 (block type: baseline vs. filtering) × 2 (stimulus position) repeated measures ANOVA. We excluded 1.1 % and another 0.9 % of the trials for the same outlier criteria as in Experiment 1 applied to RTs and MTs, respectively. For error analyses, we excluded anticipation errors (0.4 %) and distinguished two kinds of errors. Perceptual errors occurred when participants clicked on the wrong stimulus; action errors were clicks on the correct stimulus, but outside the target area.

Results

RTs, MTs, and error percentages

Regarding the perceptual component, RTs were longer in filtering than in baseline blocks (Fig. 4), $F(1,23) = 13.90$, $p = .001$, $\eta_p^2 = .38$. In addition, RTs were faster when the

Fig. 4 Mean reaction times (RTs) and movement times (MTs) of Experiment 2 as a function of task component (perceptual vs. action) and block type (baseline vs. filtering). Error bars are 95 % within-subject confidence intervals (Pfister and Janczyk 2013)

higher (target) stimulus appeared in the right (365 ms) than in the left position (379 ms), $F(1,23) = 8.70$, $p = .007$, $\eta_p^2 = .27$. The interaction of both factors approached significance, $F(1,23) = 3.02$, $p = .096$, $\eta_p^2 = .12$. Perceptual errors were very low (see Table 1), and no effect was significant, all $Fs \leq 2.23$, all $ps \geq .149$.

Regarding the action component, MTs were not affected by block type, $F(1,23) = 0.36$, $p = .552$, $\eta_p^2 = .02$, nor did block type interact with stimulus position, $F(1,23) = 0.40$, $p = .534$, $\eta_p^2 = .02$. However, there was a main effect of stimulus position, $F(1,23) = 4.89$, $p = .037$, $\eta_p^2 = .18$, reflecting faster movements to right (761 ms) than to left stimuli (774 ms). Action errors are summarized in Table 1, and no effect was significant, all $Fs \leq 0.97$, all $ps \geq .334$.

Action component: trajectory data

Trajectories are visualized in Fig. 2 (lower panel), and means of the dependent variables are summarized in Fig. 3 (right column). Statistical details can be obtained from Table 2, and there were no significant effects except for T_{max}. Maximum speed was reached later in filtering than in baseline blocks and when approaching left compared to right stimuli. Further, the difference between filtering and baseline blocks was larger for left targets.

Correlation analyses

To exclude trade-offs between RT and MT, we calculated the correlation of these variables for each participant. The individual values range from $r = -.29$ to $r = +.37$. Averaging the individual, Fisher Z-transformed values gives a correlation coefficient close to zero ($|r| < .01$).

Discussion

In Experiment 2, we measured a perceptual and an action component within one task and gathered data for both aspects from the same participants. RTs indicated that participants experienced difficulty in identifying the target stimulus in the filtering blocks, i.e., the perceptual component suffered from Garner-Interference. In contrast, measures derived from the action component (MTs and trajectory data) were largely unaffected by the block-type factor.

An exception was the larger T_{max} in filtering than in baseline blocks. However, we do not consider this finding problematic for our conclusions for several reasons. Given the amount of dependent measures we used here, this particular finding may simply reflect a type I error. This possibility is supported by the fact that in the action tasks of Experiment 1, no comparable observation was made regarding this variable, whereas the significant effect of block type in the perceptual tasks was consistently

observed in all analyses. Moreover, a Garner-Interference account would predict the opposite pattern (see the "Introduction" section). Participants should initiate a slow, controlled approach phase *earlier* in the more difficult filtering than in the easier baseline blocks. Therefore, we prefer to stay conservative and remain reluctant to interpret this single significant effect.

General discussion

Tools play an important role in human life, and recent years have brought about a major change. Traditional tools, e.g., hammers or scissors, use visible, mechanical transformations, but this is not true for the computer mouse—arguably the most often employed tool in western cultures nowadays. Several studies suggest that tools, and other external parts, eventually become part of the body schema (Botvinick and Cohen 1998; Farnè and Làdavas 2000; Iriki et al. 1996, 2001), while others suggest the opposite (Gonzalez et al. 2006, 2008; Yuan and Steed 2010). Here, we focused on a particular characteristic of natural movements, namely their resistance to task-irrelevant, but stimulus-inherent distraction. In two experiments, we asked whether mouse movements possess this characteristic as well.

Mice move smoothly: no influences of stimulus-inherent variation on mouse movements

The outcome of our experiments is clear-cut: Perceptual judgments of virtual object features suffer interference from an irrelevant stimulus dimension, but mouse movements do not. This dissociation was observed with varying start but constant end positions (Exp. 1a) and with varying end but constant start positions (Exp. 1b). Influences of task-irrelevant object features were similarly present in an action task that included a perceptual decision component (Exp. 2). Thus, Garner-Interference was consistently present in perceptual judgments, but consistently absent for mouse movements. One point to consider is that the irrelevant stimulus dimension "width" had a spatial left/right extension. Thus, the statistical effects we attribute to Garner-Interference may only arise since responses in the perceptual task, not necessarily though in the action task, were left/right as well. However, note that first, Garner-Interference in perceptual tasks has also been reported without left/right responses, but with simulated grasping movements (Ganel and Goodale 2003, Exp. 2). Secondly, in the action task of our Experiment 1b, a left/right component was also present, but still no signs of Garner-Interference emerged.

In sum, it appears that mouse movements indeed share characteristics with natural hand movements: Both are not susceptible to the type of interference investigated here,

what in turn suggests that even complex tools with virtual transformations may become part of the body schema. To the best of our knowledge, this question had only been investigated with mechanical tools so far. Related to the action/perception model (Goodale and Milner 1992), it has been suggested that the advantages of dorsal control are only available to natural, skilled, and right-handed movements (Gonzalez et al. 2006, 2008). Mouse movements, in contrast, can be construed as a candidate for ventral control, but apparently show characteristics like natural, right-handed movements. This finding fits well with a recent study where neither left-handed, nor awkward, nor tool-transformed (pliers) actions showed any sign of Garner-Interference (Janczyk et al. 2010). In other words, it appears as if all object-oriented movements—be they transformed or not—behave similarly and are perhaps controlled in a similar manner. The present experiments advance this view by showing that this conclusion also holds for the abstract transformation underlying mouse movements.

One objection would be that for our participants, mouse movements were skilled right-handed actions as they likely used this input device routinely before. Note, however, that mere exercise does not render an action suitable for dorsal control. Indeed, Gonzalez et al. (2006) suggested that left-handed grasping even for left-handers is not under dorsal control. Also, the involved transformation, and thus the feedback from the hand movements, is rather complex because hand movements are transformed into an almost perpendicular plane. To sum up, we believe that there are many reasons to be confident that, in principle, computer-mouse movements are theoretically a good candidate for reliance on perceptual information from supposedly the ventral stream. Of course, it is possible that the ventral stream comes into play with even more complex transformations. Yet, given the evidence so far, we are reluctant regarding such a prediction.

Virtual tools and real-world performance

Our results suggest that deliberate decisions where to move a cursor, but not the movement itself, are affected by the type of irrelevant stimulation studied here. Surely, these results convey some good news for applied fields. However, the most realistic situations in HCI require both, identifying the stimulus and then acting on it. Our Experiment 2 comes close to this situation and clearly the negative bias on overall performance via the perceptual component weighed in. Consequently, one may conclude that designers of PC applications and internet pages should refrain from introducing unnecessary variation of task-relevant components. However, the broader context must also be considered. In our example, only one or two target objects appeared on screen—an unrealistic situation in applied contexts such

as internet pages. In cases where attention-grabbing variations of target items enhance their perception (Bodner and MacKenzie 1997), this facilitation may outweigh the detrimental effects observed in our experiments. Hence, overall variation of task-irrelevant dimensions of target items may even facilitate performance, depending on the current task context.

Conclusions

The present findings speak to three issues. First, computer-transformed movements are not susceptible to variations of a task-irrelevant stimulus dimension, just as natural, skilled right-handed movements, and unskilled movements (Janczyk et al. 2010), suggesting a common neural substrate guiding these actions. Speculatively, this is the dorsal visual pathway (Ganel and Goodale 2003). Secondly, even tools without obvious mechanical transformations can acquire characteristics of natural movements, hence, according to this criterion, become integrated into the body schema. Finally, the present experiments suggest that in mouse-based HCI perceptual decisions where to move are affected, but actual movements are not.

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