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ORIGINAL ARTICLE

Garner-Interference in left-handed awkward grasping

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Abstract The Perception–Action Model (PAM) claims to provide a coherent interpretation of data from all areas of the visual neurosciences, most notably data from neuropsychological patients and from behavioral experiments in healthy people. Here, we tested two claims that are part of the core version of the PAM: (a) certain actions (natural, highly practiced, and right-handed) are controlled by the dorsal vision for action pathway, while other actions (awkward, unpracticed, or left-handed) are controlled by the ventral vision for perception pathway. (b) Only the dorsal pathway operates in an analytical fashion, being able to selectively focus on the task-relevant dimension of an object (Ganel and Goodale, Nature 426(6967):664–667, 2003). We show that one of these claims must be wrong: using the same test for analytical processing as Ganel and Goodale (2003), we found that even an action that should clearly be ventral (left-handed awkward grasping) shows analytical processing just as a dorsal task does (right-handed natural precision grasping). These results are at odds with the PAM and point to an inconsistency of the model.

The Perception–Action Model

Theories of the visual system often assume a functional division of labor between the dorsal pathway leading from the primary visual cortex to the posterior parietal cortex and the ventral pathway leading to the inferior temporal cortex (e.g., Ungerleider & Mishkin, 1982). One particularly influential interpretation, the Perception–Action Model (PAM; Goodale & Milner, 1992; Milner & Goodale, 1995), suggests that the ventral pathway is responsible for identifying stimuli ("vision for perception"), utilizing a scene-based frame of reference, relational metrics, and being related to consciousness and long-term memory. In contrast, the dorsal pathway is assumed to be responsible for guiding visually based actions ("vision for action"), transforming visual information in a way that allows interaction with the environment and utilizing an egocentric frame of reference, absolute metrics, and unconscious moment-to-moment representations. The PAM was initially based on the case of patient D.F. who, after hypoxia from carbon monoxide poisoning, suffered severe damage to the lateral occipital complex, while the anterior intraparietal sulcus remained intact (James, Culham, Humphrey, Milner, & Goodale, 2003). For example, D.F. showed very poor performance in perceptual tasks requiring spatial vision, but she performed similar to age-matched healthy people in tasks requiring visually guided movements (Goodale et al., 1994; Goodale, Milner, Jakobson, & Carey, 1991). Importantly, the opposite pattern was observed in the patient R.V. suffering from optic ataxia following bilateral lesions of the occipitoparietal cortex (Goodale et al., 1994).

Even though the PAM was originally based on neurological conditions, its core assumptions should certainly apply to healthy people as well. Among the earliest studies to test this was the one conducted by Aglioti, DeSouza, and Goodale (1995). This study was meant to show that size-contrast illusions do affect vision for perception, but not vision for action. Although this study triggered numerous subsequent studies, this approach has also been subject of a

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controversial debate (Bruno, 2001; Carey, 2001; Franz, 2001; Franz & Gegenfurtner, 2008; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000; Schenk, Franz, & Bruno, 2011; Smeets & Brenner, 2006; Westwood & Goodale, 2011). Given this situation, researchers sought to find independent evidence that corroborates the PAM in healthy people.

Garner-Interference as a test for analytic processing

A different approach to test the PAM in healthy people was introduced by Ganel and Goodale (2003) who argued that vision for perception and vision for action process objects and their dimensions differently. Consider the case of a cuboid—a simple three-dimensional object. The argument is that only vision for action is capable of processing one dimension without being influenced by the other two dimensions, that is, in an 'analytical' way. In contrast, vision for perception can only process a particular dimension in relation to the other dimensions, that is, in a 'holistic' way.[1] Consequently, the particular task (and thus the required response) would determine whether an object is processed analytically or holistically. If, for instance, a person is asked to grasp a cuboid along its width (a task assumed to require the vision for action system), the absolute size of the relevant dimension can be accessed directly. In contrast, if a person is asked to report the width (i.e., characteristics of the relevant dimension), vision for perception is required. Thus, the cuboid is first perceived as a whole and subsequent additional processing is required to extract the relevant dimension. In other words: vision for perception combines the three dimensions and allows one to perceive the object as a whole, while vision for action takes only into account the dimension relevant for successfully executing the action task.

To test this idea, Ganel and Goodale (2003) utilized variants of Garner's speeded-classification task (Garner, 1974, 1978). In such tasks, participants are asked to identify the characteristics of a specific 'relevant' dimension 'R' of a target stimulus as quickly as possible, while ignoring the characteristics of another 'irrelevant' dimension 'I'. Both dimensions R and I can attain one of two values and their combination yields a set of four different target stimuli, that is, $\{R_1I_1, R_2I_1, R_1I_2, R_2I_2\}$. In Ganel and Goodale's study, target stimuli were cuboids which varied with regard to their length and their width (but not their height). Performance was compared between two different experimental conditions. In the 'baseline' condition, only the relevant dimension R varied from trial to trial, while the irrelevant dimension I was kept constant. This implies that only two of the four target stimuli were used in this condition, namely either the subset $\{R_1I_1, R_2I_1\}$ or the subset $\{R_1I_2, R_2I_2\}$. In contrast, in the 'filtering' condition (see also Posner, 1964), the whole set of target stimuli was used, implying that both the relevant and the irrelevant dimensions varied from trial to trial. The reasoning behind comparing baseline and filtering conditions is that performance in the filtering condition should be worse compared to the baseline condition, if a target stimulus can only be processed holistically ("Garner-Interference"). In this case, participants cannot attend selectively to the relevant dimension and performance is negatively affected when attributes or features of other (irrelevant) dimensions vary simultaneously.

Ganel and Goodale (2003) tested for Garner-Interference in two different tasks. In the *perceptual speeded-classification task*, participants were asked to judge as quickly as possible the width of the target stimulus by pressing one of two response buttons. In the *grasping task*, they were asked to grasp the target stimulus as quickly as possible across its width with a right-handed precision grip. Consistent with the reasoning laid out above, Garner-Interference (i.e., longer RTs in the filtering condition compared to the baseline condition) was only found for the perceptual speeded-classification task, indicating a holistic representation of the target stimuli. No Garner-Interference was observed in the grasping task. This pattern was replicated even in dual-task situations (Janczyk & Kunde, 2010; Kunde, Landgraf, Paelecke, & Kiesel, 2007) and—at first glance—appears to be in line with the PAM.

However, another core assumption of the PAM is that not all actions are guided by the dorsal vision for action system, but that some actions are mainly guided by the ventral vision for perception pathway. For example, Goodale et al. (1991) assumed that turning a hand-held card to match the orientation of a slot is guided by the vision for perception pathway and Haffenden and Goodale (1998) assumed that indicating the size of a target stimulus by using index finger and thumb (without seeing the hand) is a "manual 'read-out' of what they [participants] perceive" (p. 125). Most importantly for the present purposes, even some actions truly interacting with a target stimulus, such as awkward grasping (e.g., grasping with the right thumb and ring finger) and left-handed grasping[2] are assumed to

[1] Such reasoning is also implicitly assumed in studies using visual illusions. If, for instance, participants are asked to grasp the target circle of an Ebbinghaus illusion, the PAM says that vision for action determines the size of the target circle without being influenced by the neighboring context circles. If, however, participants are asked to manually estimate the size of the target circle, the PAM states that vision for perception codes the size of the target circle relative to the neighboring context circles.

[2] Note that in the original work this was even claimed true for left-handers.

be guided by the ventral vision for perception pathway (cf. Gonzalez, Ganel, & Goodale, 2006; Gonzalez, Ganel, Whitwell, Morrissey, & Goodale, 2008; Goodale, 2008).

If the two premises were correct—(1) certain actions are controlled by the ventral pathway and (2) ventral processing yields Garner-Interference—it follows that those target-directed actions should also suffer from Garner-Interference. Notably, this was neither the case for awkward grasping, nor for left-handed grasping, nor for grasping with pliers (Janczyk, Franz, & Kunde, 2010), raising some doubts concerning the validity of one (or both) of the premises. However, a potential drawback of the study by Janczyk et al. (2010) is that no kinematics were measured and thus the conclusions were only based on analyzing time to initiate and the subsequent movement time. Yet, differences in kinematic measures cannot be excluded (see Hesse, de Grave, Franz, Brenner, & Smeets, 2008).

There is another potential problem for all aforementioned studies that assessed Garner-Interference in the present context, namely that the comparison of baseline and filtering conditions is confounded with presenting two or four target stimuli (see also Janczyk & Kunde, 2012, for pointing out this problem). Thus, because only vision for perception is assumed to access long-term representations of target templates, this confound may also explain the observed performance differences in perceptual but not action tasks. However, Garner's speeded-classification task allows us to additionally assess performance in a so-called 'correlated' condition. Here, both dimensions vary in a perfectly correlated manner and participants can thus use either dimension to determine the correct response. Importantly, only two out of the four target stimuli are used in the correlated conditions, that is, either the subset $\{R_1I_1, R_2I_2\}$ or the subset $\{R_1I_2, R_2I_1\}$. If a target stimulus is processed holistically, then performance should be *better* in the correlated condition than in the baseline condition (which should be better than in the filtering condition). This pattern has been reported for two-dimensional rectangular stimuli (Felfoldy, 1974), but has never been shown with natural, three-dimensional stimuli such as those used in the aforementioned studies.

The present study

The experiments we report here took into account these concerns. In Experiment 1, we aimed at replicating the main findings of Ganel and Goodale (2003) while additionally using the correlated condition. In Experiment 2, we had participants grasp target stimuli with the thumb and ring finger (awkward grasp) of their left hand. In other words, we combined awkward and left-handed grasping, which were both attributed to ventral processing in previous work (Gonzalez et al., 2006, 2008; Goodale, 2008), and thus created a so to speak 'decidedly ventral' grasping task. In addition to latency-based measures, in both experiments kinematics were considered as additional dependent measures. If both Ganel and Goodale's and Gonzalez et al.'s claims were true, the following outcomes can be expected: firstly, in Experiment 1, Garner-Interference should emerge in a perceptual speeded-classification task but not in right-handed precision grasping, thus essentially a replication of Ganel and Goodale's study. Secondly, we should also find Garner-Interference in left-handed awkward grasping in Experiment 2.

Experiment 1

Experiment 1 was a close replication of the study by Ganel and Goodale (2003). For this, we followed their method in most parts. The main difference, however, was that in our experiment participants performed a correlated condition in addition to the baseline and filtering condition.

Materials and methods

Participants

Twenty-four students from the University of Hamburg participated in Experiment 1 (17 female; mean age = 22.0 years, range = 19–28 years, SD = 3.3). They were all right-handed by self-report and reported normal or corrected-to-normal vision. Written informed consent was obtained from all participants. All experiments were conducted in accordance with the 1964 Declaration of Helsinki and with the ethical guidelines of the German Psychological Society (DGPs) and the Professional Association of German Psychologists (BDP) (2005, C.III). Participants received either course-credits or monetary compensation (€8 per hour).

Target stimuli and experimental setup

Target stimuli had identical dimensions as those used in earlier studies (e.g., Ganel & Goodale, 2003). Thus, cuboids with two different widths (relevant dimension: $R_1 = 30$ and $R_2 = 35.7$ mm) and lengths (irrelevant dimension: $I_1 = 63$ and $I_2 = 75$ mm), but constant height (15 mm) were used. Orthogonal combination of each length and width resulted in four different target stimuli.

All participants performed both a grasping task and a perceptual speeded-classification task. In the grasping task, infrared emitting diodes (IRED) were attached to the nail of the right thumb and index finger. IRED position data were sampled at 200 Hz via an Optotrak Certus (Northern Digital Inc., Waterloo, ON, Canada) movement analysis system. An additional IRED attached to the table in the vicinity of the target area enabled exact detection of the moment when the target stimulus was touched. To this end, each target had a little mirror on the side facing the IRED, reflecting the signal of the embedded IRED, which was then registered by the Optotrak. As soon as the target stimulus was moved, the Optotrak received a position displacement signal. The displacement signal was then converted into a velocity signal. If the velocity signal exceeded a certain threshold, this was taken as an indicator that the target stimulus had been contacted (see below and Fig. 3f of Franz, Scharnowski, & Gegenfurtner, 2005).

Experimental procedures were run on a Fujitsu Celsius computer (Fujitsu Technology Solutions, Tokyo, Japan) and response buttons for the perceptual task were custom-made and had high temporal accuracy (Jonas, Eloka, Stephan, & Franz, 2014). They were 25 mm apart and built in a rectangular plastic box. The plastic box was placed at an angle of approximately 45° to the target stimulus' presentation line. Each of the response buttons was connected to the digital input channels of a DT 9812 USB module (Data Translation, Marlboro, MA, USA). The experiment was controlled from within Matlab version R2010b (Mathworks, Natick, MA, USA) with the use of the Data Acquisition Toolbox, the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997), and the Optotrak Toolbox by V. H. Franz (http://webapp6.rrz.uni-hamburg.de/allpsy/vf/OptotrakToolbox).

Participants were seated comfortably on an adjustable chair in front of a table on which the target stimuli were placed. To avoid automatized grasping strategies, the location (within a circle of radius 5 cm) and the orientation (between 0° and 10°) of the target stimulus varied from trial to trial. The orientation of the target stimulus was defined as the angle between the sagittal line and the line running through the transversal axis of the target stimulus.

The visibility of the target stimulus was controlled by liquid-crystal shutter goggles (Milgram, 1987). The goggles could either be transparent or opaque. When transparent, participants could see the target stimulus as well as their hand. When opaque, vision was prevented.

Experimental procedure

The right-handed precision grasping and the perceptual speeded-classification task were performed in a single session of approximately 70 min. Each task was composed of six blocks, with two successive blocks implementing one of the three conditions (correlated, baseline, filtering). In the first block of the correlated condition only the $R_1 = 30$ mm $\times$ $I_1 = 63$ mm and $R_2 = 35.7$ mm $\times$ $I_2 = 75$ mm stimuli and in the second block only the $R_2 = 35.7$ mm $\times$ $I_1 = 63$ mm and $R_1 = 30$ mm $\times$ $I_2 = 75$ mm stimuli were presented. In the first baseline block only the two stimuli of $I_1 = 63$ mm length and in the second baseline block only the two stimuli of $I_2 = 75$ mm length were presented. In the two filtering blocks, all stimuli were presented. Task order and condition order were counterbalanced across participants.

Prior to each new block, participants were familiarized with the target stimuli of the upcoming block. Each block was preceded by four (unanalyzed) practice trials; the experimental blocks were composed of 24 trials each and the target stimuli were shown equally often in a random order (i.e., 6 times in the filtering condition and 12 times in the correlated and the baseline conditions). In total, each task consisted of 168 trials.

In the grasping task, participants placed their hand on a pinhead (starting position) attached to the table directly in front of the participant. Each trial started with the shutter goggles opaque. Participants were asked to reach out and grasp the target stimulus across its width with the right thumb and index finger (precision grip), lift it, and then return the hand to the start position. Movement was to be initiated as soon as the shutter goggles opened and to be performed as quickly as possible. The shutter goggles closed when the participants returned their hand to the start position. After closure of the shutter goggles, the experimenter placed the new target stimulus on the target position and initiated the next trial.

In the perceptual speeded-classification task, participants placed the right index finger on the left response key and the right middle finger on the right response key and each trial started with the shutter goggles opaque. Participants were asked to judge the width of the stimuli by pressing the appropriate response key as soon as the shutter goggles opened. Assignment of response keys to the width of the target stimulus was counterbalanced across participants. In order to achieve a comparable haptic feedback to the grasping task, as in the study by Ganel and Goodale (2003), participants reached out and grasped the target stimulus after they had pressed the response key. Afterwards, they placed their fingers back on the response keys. Shutter goggles stayed open for a duration of 2,000 ms in total. After closure of the shutter goggles, the experimenter placed the new target stimulus on the target position and initiated the next trial.

Data analysis

In the right-handed precision grasping task, movement onset was defined by a velocity criterion. The first frame in which the index finger or the thumb exceeded a velocity threshold of 0.025 m/s was defined as movement onset. Time to initiate movement was defined as the time from the opening of the shutter goggles to movement onset. Touch of the target stimulus was again defined by a velocity signal made possible by the mirror attached to the stimuli, namely as the first frame in which this signal exceeded a velocity threshold of 0.01 m/s. Time to complete movement was defined as the time between the opening of the shutter goggles and the touch of the target stimulus. Maximum grip aperture (MGA) was defined as the maximum distance between index finger and thumb during the grasping movement. Time to reach MGA was defined as the time between the opening of the shutter goggles and time at which MGA was reached. RT for the perceptual speeded-classification task was defined as the time between the opening of the shutter goggles and the button press.

For analysis of grasping measures, those experimental trials were eliminated where time to complete movement deviated from the corresponding cell mean (calculated separately for each participant and condition) by more than 2 SDs. The remaining experimental trials were used for the analysis of all grasping measures. For analysis of RTs in the perceptual speeded-classification task, erroneous experimental trials were excluded first. Afterwards, as for the analysis of grasping measures, those experimental trials were eliminated where RTs deviated from the corresponding cell mean (calculated separately for each participant and condition) by more than 2 SDs.

In order to compensate for possible violations of the sphericity assumption, always Greenhouse–Geisser (Greenhouse & Geisser, 1959) corrected p values are reported and departure from sphericity is indicated by ε. A significance level of $\alpha = 0.05$ was adopted throughout the manuscript.

Results

In order to allow for a direct comparison of our results and those of Ganel and Goodale (2003), we first performed the exact same analyses as Ganel and Goodale did. To do so, we omitted the (additionally tested) correlated condition. Statistics and p values based on these analyses are presented in Table 1 along with statistics and p values from the study by Ganel and Goodale (2003). As can easily be seen, our results replicate those of Ganel and Goodale. In Fig. 1b the strength of Garner-Interference found in our study can be visually compared to the strength of the Garner-Interference reported by Ganel and Goodale (2003), again showing that we replicated Ganel and Goodale (2003). All other analyses that are presented in the following sections were based on all three conditions (i.e., correlated, baseline, and filtering).

Perceptual speeded-classification task

As outliers, 4.3 % of the experimental trials were discarded. Results for the remaining experimental trials are depicted in Fig. 1a. Participants responded fastest in the correlated condition (mean = 468 ms) and slowest in the filtering condition (mean = 540 ms). RTs for the baseline condition lay in between (mean = 498 ms). Accordingly,

Table 1 Comparison of results from our Experiment 1 with Ganel and Goodale (2003)

Task	DV	Effect	Our Experiment 1		Ganel & Goodale (2003)		
			Statistic	p value	Statistic	p value	Reference
Perceptual speeded-classification	RT	Condition	$t_{23} = 4.05$	<0.001	$t_{11} = 2.49$	<0.05	p. 665
Perceptual speeded-classifications vs. Right-handed precision grasping	RT and time to complete movement	Interaction 2 (task) × 2 (condition)	$F_{1,23} = 21.99$	<0.001	$F_{1,11} = 7.93$	<0.05	p. 665
Right-handed precision grasping	Time to complete movement	Condition	$t_{23} = 0.38$	>0.1	$t_{11} = 0.3$	>0.1	p. 665
	MGA	Main effect width	$F_{1,23} = 137.97$	<0.001	$F_{1,10} = 119$	<0.001	p. 666
	MGA	Main effect condition	$F_{1,23} = 0.47$	>0.1	$F_{1,10} = 0.2$	>0.1	p. 666
	MGA	Interaction 2 (width) × 2 (condition)	$F_{1,23} = 3.17$	0.088	$F_{1,10} = 0.1$	>0.1	p. 666
	MGA	Main effect length (irrelevant dimension)	$t_{23} = 1.04$	>0.1	$t_7 = 0.65$	>0.1	p. 666 Fig. 4

For comparison of the results of our Experiment 1 with those of Ganel and Goodale (2003), we applied exactly the same analyses as had been performed by Ganel and Goodale. For this, we excluded the correlated condition (which was not measured by Ganel and Goodale). The pattern of our results are identical to those obtained by Ganel and Goodale

DV dependent variable, *RT* response time, *MGA* maximum grip aperture

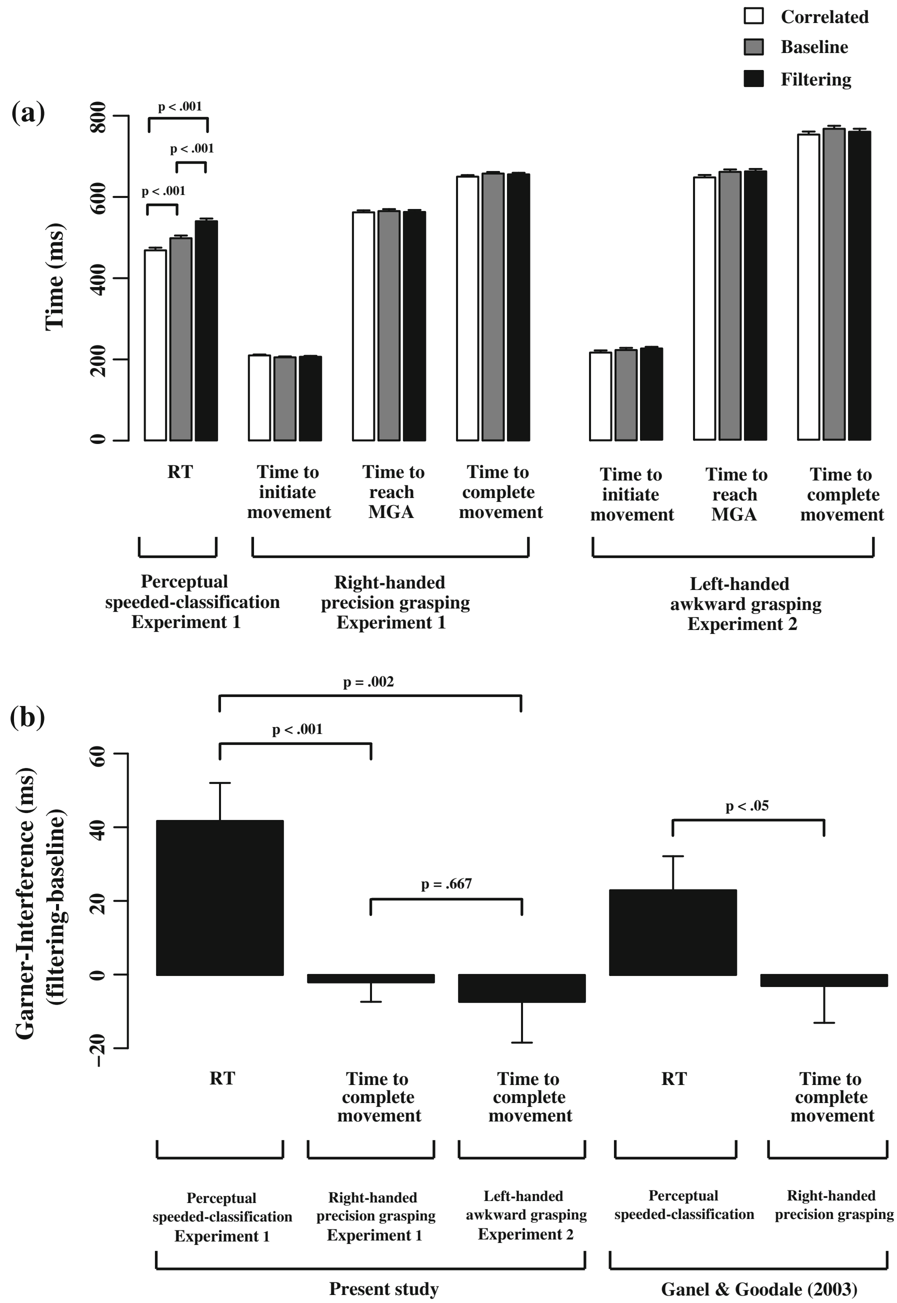

Fig. 1 In **a** RTs for the perceptual speeded-classification task and time-based grasping measures (time to initiate movement, time to reach MGA, time to complete movement) for the right-handed precision grasping task of Experiment 1 and for the left-handed awkward grasping task of Experiment 2 are shown as a function of condition (correlated, baseline, and filtering). *Error bars* are $SEM^{L\&M}$ as calculated by Loftus and Masson (1994; see also Franz & Loftus, 2012). In **b** Garner-Interference (calculated as the difference between filtering and baseline conditions) is depicted for perceptual speeded-classification, right-handed precision grasping, and left-handed awkward grasping. For purposes of comparison, we also plotted Garner-Interference for perceptual speeded-classification and right-handed precision grasping as reported in the study by Ganel and Goodale (2003). *Error bars* are *SEM* of the differences between filtering and baseline condition. *Error bars* for Ganel and Goodale's plots were calculated via $SEM_{diff} = diff/t$

the ANOVA revealed a significant main effect of condition ($F(2, 46) = 29.91, p < 0.001, \eta_p^2 = 0.57, \varepsilon = 0.85$). Paired samples *t* tests revealed that the difference between the baseline and the correlated condition was significant ($t(23) = 4.23$, $p < 0.001$, $d = 0.86$), as was the difference between the baseline and the filtering condition ($t(23) = 4.05$, $p < 0.001$, $d = 0.83$). This difference, that is the Garner-Interference, was even somewhat larger in our study than reported by Ganel and Goodale (2003); see also Fig. 1b. The difference between the filtering and the correlated condition was also significant ($t(23) = 7.04$, $p < 0.001$, $d = 1.44$).

The mean percentage of errors was 3.7 % in the correlated condition, 5.3 % in the baseline condition, and 6.1 % in the filtering condition. The corresponding ANOVA revealed no significant effect of condition ($F(2, 46) = 2.50$, $p = 0.095$, $\eta_p^2 = 0.10$, $\varepsilon = 0.97$).

Grasping task

As outliers, 4.9 % of the experimental trials were discarded. Results for the remaining experimental trials are depicted in Fig. 1a. Visual inspection of time to complete movement[3] suggests no differences between the correlated (mean = 649 ms), baseline (mean = 657 ms), and filtering (mean = 655 ms) conditions and the effect of condition was not significant ($F(2, 46) = 1.10$, $p = 0.340$, $\eta_p^2 = 0.05$, $\varepsilon = 0.99$). Time to initiate movement was also very similar for the correlated (mean = 209 ms), baseline (mean = 205 ms), and filtering (mean = 206 ms) conditions and the effect of condition was not significant ($F(2, 46) = 1.14$, $p = 0.326$, $\eta_p^2 = 0.05$, $\varepsilon = 0.91$). Finally, time to reach MGA did not vary much across the correlated (mean = 562 ms), baseline (mean = 565 ms), and filtering (mean = 563 ms) conditions and again there was no significant effect of condition ($F(2, 46) = 0.11$, $p = 0.889$, $\eta_p^2 < 0.01$, $\varepsilon = 0.94$).

In addition to the time analyses, we analyzed the influence of width and condition on MGA. The 2 (width) × 3 (condition) ANOVA on MGA gave results similar to those reported by Ganel and Goodale (2003). We also found a main effect of width ($F(1, 23) = 129.75$, $p < 0.001$, $\eta_p^2 = 0.85$), but no effect of condition ($F(2, 46) = 0.31$, $p = 0.719$, $\eta_p^2 = 0.01$, $\varepsilon = 0.94$) and no interaction ($F(2, 46) = 2.31$, $p = 0.113$, $\eta_p^2 = 0.09$, $\varepsilon = 0.95$).

Comparison between perceptual speeded-classification and right-handed precision grasping

To gain further insights into the interaction between the two tasks and the three conditions, we compared RTs of the perceptual speeded-classification task with time to complete movement in grasping with a 2 (task) × 3 (condition) ANOVA. As expected, we found a significant effect of task ($F(1, 23) = 49.96$, $p < 0.001$, $\eta_p^2 = 0.69$). It took participants about 150 ms longer to complete movements in the grasping task (mean = 654 ms) than to respond in the perceptual speeded-classification task (mean = 502 ms). The ANOVA also revealed a significant effect of condition ($F(2, 46) = 20.35$, $p < 0.001$, $\eta_p^2 = 0.47$, $\varepsilon = 0.79$). Most importantly, task and condition interacted significantly ($F(2, 46) = 26.90$, $p < 0.001$, $\eta_p^2 = 0.54$, $\varepsilon > 0.99$).

We further compared RTs in perceptual speeded-classification with time to initiate movement in grasping with a 2 (task) × 3 (condition) ANOVA. As expected, we found a significant effect of task ($F(1, 23) = 474.95$, $p < 0.001$, $\eta_p^2 = 0.95$). Time to initiate movement in the grasping task (mean = 207 ms) was less than half the RT in the perceptual speeded-classification task (mean = 502 ms). The ANOVA also revealed a significant effect of condition ($F(2, 46) = 21.46$, $p < 0.001$, $\eta_p^2 = 0.48$, $\varepsilon = 0.80$) and again task and condition interacted significantly ($F(2, 46) = 34.22$, $p < 0.001$, $\eta_p^2 = 0.60$, $\varepsilon = 0.96$).

Discussion

Experiment 1 was run to replicate the main findings of Ganel and Goodale (2003), that is, we tested whether Garner-Interference can be found in a perceptual speeded-classification task, but not in right-handed precision grasping. A novel aspect was that we also used the correlated condition (see Garner, 1974, 1978) to find further evidence for the holistic nature of ventral vision for perception processing. The results converge nicely with those reported by Ganel and Goodale (see also Table 1 for a comparison). Firstly, Garner-Interference was present in the perceptual speeded-classification task with both (1) better performance in the correlated than in the baseline condition and (2) worse performance in the filtering than in the baseline condition. This result supports the notion that vision for perception cannot process object dimensions in an analytical manner. Instead, objects appear to be perceived/processed as a whole. Secondly, in the grasping task, no effect of these conditions on time-based grasping measures and MGA was found. Thirdly, our results showed an interaction between the two tasks (perceptual speeded-classification versus right-handed precision grasping) and the three conditions. These results suggest that Garner-Interference does not come into play in right-handed precision grasping.

In sum, these results demonstrate that we can, in principle, find evidence for Garner-Interference in tasks assumed to be associated with the ventral vision for perception pathway but no Garner-Interference for tasks assumed to be associated with the dorsal vision for action pathway.

Experiment 2

Remember that control of left-handed (Gonzalez et al., 2006) and awkward (Gonzalez et al., 2008) grasping was attributed to processes of vision for perception (cf. Goodale, 2008). Hence, these tasks should suffer from Garner-Interference (Ganel & Goodale, 2003), but in one study this was not the case (Janczyk et al., 2010). However, this study might not be totally conclusive as no kinematic measures were recorded and analyzed. In Experiment 2, we created a task that (in the framework of the PAM) should clearly be guided by vision for perception, because we combined left-handed and

[3] Time to complete movement was the prominent dependent variable in the original study (Ganel & Goodale, 2003). For that reason, results for time to complete movement will always be presented first. Note that in the original study this variable was refered to as "reaction time to complete movement".

awkward grasping (thus grasping with the thumb and ring finger of the left hand) and tested whether this task suffers from Garner-Interference. Again, we included the correlated condition and recorded kinematic measures. If the PAM is correct, Garner-Interference should be observed for this particular type of grasping.

Materials and methods

Participants

Twenty-four new participants (18 female; mean age = 25, range = 19–36 years, SD = 4.3) from the same pool as in Experiment 1 took part in this experiment.

Target stimuli and experimental setup, experimental procedure, data analysis

The experiment was in most aspects identical to the grasping task of Experiment 1. The main difference was that participants performed a grasping task in which they were required to reach for and grasp the target stimulus with the thumb and the ring finger of their left hand, that is, a left-handed awkward grip (instead of a right-handed precision grip). Consequently, IRED were attached to the thumb and ring finger of the left hand.

Results

As outliers, 4.7 % of the experimental trials were discarded. Results of the time analyses on the remaining experimental trials are illustrated in Fig. 1a. As can be seen, time to complete movement did not vary much across the correlated (mean = 751 ms), baseline (mean = 766 ms), and filtering (mean = 758 ms) conditions and the effect of condition failed to reach significance ($F(2, 46) = 0.93$, $p = 0.399$, $\eta_p^2 = 0.04$, $\varepsilon = 0.98$). Also, time to initiate movement was very similar for the correlated (mean = 216 ms), baseline (mean = 222 ms), and filtering conditions (mean = 225 ms) and the effect of condition was not significant ($F(2, 46) = 1.31$, $p = 0.279$, $\eta_p^2 = 0.05$, $\varepsilon = 0.84$). Similarly, time to reach MGA did not vary much across the correlated (mean = 646 ms), baseline (mean = 660 ms), and filtering (mean = 661 ms) conditions and the effect of condition was not significant ($F(2, 46) = 1.91$, $p = 0.162$, $\eta_p^2 = 0.08$, $\varepsilon = 0.95$).

Again, in addition to the time analyses, we performed a 2 (width) × 3 (condition) ANOVA on MGA and found results similar to the right-handed precision grasping task in Experiment 1. The ANOVA revealed a main effect of width ($F(1, 23) = 89.29$, $p < 0.001$, $\eta_p^2 = 0.80$), but neither a significant effect of condition ($F(2, 46) = 0.13$, $p = 0.864$, $\eta_p^2 = 0.01$, $\varepsilon = 0.95$) nor a significant interaction ($F(2, 46) = 1.58$, $p = 0.221$, $\eta_p^2 = 0.06$, $\varepsilon = 0.83$).

Comparison between perceptual speeded-classification (Experiment 1) and left-handed awkward grasping (Experiment 2)

We performed a 2 (task) × 3 (condition) mixed ANOVA on RTs (from the perceptual speeded-classification task in Experiment 1) and time to complete movement (from the left-handed awkward grasping task in Experiment 2). It took participants about 250 ms longer to complete movements in the grasping task (mean = 758 ms) than to respond in the perceptual speeded-classification task (mean = 502 ms) yielding a significant effect of task ($F(1, 46) = 63.86$, $p < 0.001$, $\eta_p^2 = 0.58$). The ANOVA also revealed a significant effect of condition ($F(2, 92) = 15.92$, $p < 0.001$, $\eta_p^2 = 0.26$, $\varepsilon = 0.95$) and task and condition again interacted significantly ($F(2, 92) = 11.72$, $p < 0.001$, $\eta_p^2 = 0.20$, $\varepsilon = 0.95$).

The same analysis was repeated using time to initiate movements (instead of time to complete movements). Time to initiate movements in the grasping task (mean = 221 ms) was less than half the RTs in the perceptual speeded-classification task (mean = 502 ms) yielding a significant effect of task ($F(1, 46) = 327.28$, $p < 0.001$, $\eta_p^2 = 0.88$). The ANOVA also revealed a significant effect of condition ($F(2, 92) = 27.57$, $p < 0.001$, $\eta_p^2 = 0.38$, $\varepsilon = 0.86$) and task and condition interacted significantly ($F(2, 92) = 17.22$, $p < 0.001$, $\eta_p^2 = 0.27$, $\varepsilon = 0.86$).

Comparison between right-handed precision grasping (Experiment 1) and left-handed awkward grasping (Experiment 2)

To compare the grasping tasks of Experiment 1 and 2, we first ran 2 (task) × 3 (condition) mixed ANOVAs with the relevant time-based grasping measures as dependent variables. Movements were completed earlier in right-handed precision grasping (mean = 654 ms) than in left-handed awkward grasping (mean = 758 ms) yielding an effect of task ($F(1, 46) = 8.50$, $p = 0.005$, $\eta_p^2 = 0.16$).We found no main effect of condition ($F(2, 92) = 1.76$, $p = 0.178$, $\eta_p^2 = 0.04$, $\varepsilon = 0.99$) and no significant interaction between task and condition ($F(2, 92) = 0.18$, $p = 0.837$, $\eta_p^2 < 0.01$, $\varepsilon = 0.99$). Time to initiate movements was very similar for right-handed precision grasping (mean = 207 ms) and left-handed awkward grasping (mean = 221 ms) and the effect of task was not significant ($F(1, 46) = 2.30$, $p = 0.136$, $\eta_p^2 = 0.05$). Also, neither the main effect of condition ($F(2, 92) = 0.37$, $p = 0.674$, $\eta_p^2 = 0.01$, $\varepsilon = 0.92$) nor the interaction between task and condition ($F(2, 92) = 2.16$, $p = 0.126$, $\eta_p^2 = 0.05$, $\varepsilon = 0.92$) reached significance. Participants reached MGA earlier in right-handed precision grasping (mean = 563 ms) than in left-handed awkward grasping (mean = 655 ms), yielding an effect of task

($F(1,\ 46) = 7.42$, $p = 0.009$, $\eta_p^2 = 0.14$). Importantly, however, neither the effect of condition ($F(2, 92) = 1.49$, $p = 0.232$, $\eta_p^2 = 0.03$, $\varepsilon = 0.95$) nor the interaction between task and condition ($F(2, 92) = 0.89$, $p = 0.411$, $\eta_p^2 = 0.02$, $\varepsilon = 0.95$) were significant. As we were also interested in when MGA was reached *relative* to movement execution, we calculated time to reach MGA as the percentage of movement time (time to complete movement − time to initiate movement) and conducted the same ANOVA on these values. In the right-handed precision grasping task MGA was reached after 79.5 % and in the left-handed awkward grasping task MGA was reached after 80.6 % of the movement and the effect of task was not significant ($F(1, 46) = 0.35$, $p = 0.558$, $\eta_p^2 = 0.01$). Also, the main effect of condition ($F(2, 92) = 0.56$, $p = 0.568$, $\eta_p^2 = 0.01$, $\varepsilon = 0.95$) and the interaction between task and condition ($F(2,\ 92) = 2.28$, $p = 0.111$, $\eta_p^2 = 0.05$, $\varepsilon = 0.95$) failed to reach significance.

Finally, we compared the grasping tasks in Experiments 1 and 2 with respect to MGA and ran a 2 (task) × 2 (width) × 2 (length) × 3(condition) mixed ANOVA. Importantly, we found no main effect of task ($F(1,\ 46) = 0.43$ $p = 0.518$, $\eta_p^2 = 0.01$). As expected, width influenced the MGA significantly ($F(1,\ 46) = 216.89$, $p < 0.001$, $\eta_p^2 = 0.83$) but neither length ($F(1, 46) = 0.24$, $p = 0.629$, $\eta_p^2 = 0.01$) nor condition ($F(2,\ 92) = 0.16$, $p = 0.851$, $\eta_p^2 < 0.01$, $\varepsilon = 0.99$) yielded significant effects. Interestingly, the two-way interaction between width and condition ($F(2, 92) = 3.46$, $p = 0.040$, $\eta_p^2 = 0.07$, $\varepsilon = 0.92$) as well as the three-way interaction between width, length, and condition ($F(2,\ 92) = 13.33$, $p < 0.001$, $\eta_p^2 = 0.23$, $\varepsilon = 0.79$) were significant. All nine other interactions failed to reach significance (all ps ≥ 0.096).

Discussion

As both left-handed grasping and awkward grasping supposedly are guided by ventral vision for perception (Goodale, 2008; Gonzalez et al., 2006, 2008), this should even more apply to left-handed awkward grasping. In turn, this grasping type should be affected by Garner-Interference. However, our results tell a different story. For none of the grasping measures (i.e., time-based measures and kinematic measures such as MGA) any signs of Garner-Interference were observed. In other words, all dependent measures were statistically indistinguishable between the correlated, the baseline, and the filtering condition. Still, we found that MGA depended on the width of the target stimulus, indicating that in left-handed awkward grasping MGA is also related to the width of the target stimulus, just as in right-handed precision grasping.

Importantly, our results showed an interaction between the two tasks (perceptual speeded-classification versus left-handed awkward grasping) and the three conditions. These results suggest that, contrary to the prediction of the PAM, Garner-Interference plays no role in left-handed awkward grasping, therefore indicating that the left-handed awkward grasping seem to be guided by the same processes as right-handed precision grasping.

The comparison between right-handed precision grasping and left-handed awkward grasping neither showed an interaction between task and condition with respect to the time to complete movement nor with respect to time to initiate movement. This finding points to a considerable similarity of the processes at work in right-handed precision grasping and left-handed awkward grasping. Further evidence for this conclusion is provided by the fact that the time at which MGA was reached, calculated as percentage of movement time, did not differ between the two grasping types. Also, MGA was scaled similarly for right-handed precision grasping and left-handed awkward grasping.

Surprisingly, we found evidence that MGA is modulated by the interaction between width, length, and condition. Note that this result was independent of grip type. This finding gives some indication that grasping may not depend on the most task-relevant dimension alone, as proposed by Ganel and Goodale (2003), but can also take into account other object dimensions (see also Janczyk & Kunde, 2014).

Taken together, our results indicate that no Garner-Interference was present in the left-handed awkward grasping task. They also indicate that right-handed precision grasping and left-handed awkward grasping show surprisingly similar patterns. Finally, our data suggest that grasping, right-handed precision grasping as well as left-handed awkward grasping, may not depend on analytical processing exclusively, but can be influenced by seemingly task-irrelevant object dimensions.

General discussion

The present study was designed to examine one crucial aspect of the PAM's internal consistency. In Experiment 1, we replicated the study by Ganel and Goodale (2003) and additionally employed a correlated condition to avoid confounds in stimulus number between the baseline and filtering conditions (see also Janczyk & Kunde, 2012). In accordance with Ganel and Goodale (2003), we found clear evidence for Garner-Interference in the perceptual speeded-classification task. Also, and again in accordance with Ganel and Goodale (2003), no differences in any grasping measure were found between the correlated, baseline, and filtering conditions when participants were asked to reach for and grasp the stimuli. Ganel and Goodale took this dissociation as evidence for the involvement of two different characteristics underlying these two tasks. They propose that in the perceptual speeded-classification task, the dimensions of the target stimuli are processed in a holistic manner; however, in the action task, analytical processing takes only the relevant dimension into account while the other dimensions are ignored, thus leading to similar performance for the three conditions.

The interpretation that only vision for action processes dimensions of an object in an analytical fashion, while vision for perception treats them in a holistic fashion (Ganel & Goodale, 2003), is a mainstay of the PAM. A second assumption states that not all actions are controlled by the dorsal vision for action pathway, but only natural, highly practiced, and right-handed actions are. In contrast, awkward, unpracticed, or left-handed actions are guided by the ventral vision for perception pathway (Gonzalez et al., 2006, 2008; Goodale 2008). In Experiment 2, we therefore asked participants to grasp the target stimuli with a left-handed awkward grip. If the claim holds that Garner-Interference distinguishes between vision for action and vision for perception, Garner-Interference should certainly emerge in this combined task, because even left-handed and awkward grasping alone are believed to be controlled by processes of vision for perception. Contrary to this prediction, we found no evidence for Garner-Interference in left-handed awkward grasping in any of the dependent measures we considered, even though we additionally employed the correlated condition to enhance the probability to find Garner-Interference. Thus, our results clearly point to an inconsistency in the theory and as a consequence we suggest considering the following scenarios.

Assuming that the Garner paradigm distinguishes between vision for action and vision for perception, our results are incompatible with the idea put forward by Gonzalez et al. (2006, 2008) that left-handed awkward grasping is guided by vision for perception. This has also been suggested by Janczyk et al. (2010; see also Janczyk, Pfister, & Kunde, 2013) who tested for Garner-Interference in left-handed grasping, awkward grasping, tool grasping, and mouse movements separately and never found Garner-Interference for any kind of these action tasks. Thus, they argued that there is no need to distinguish between the two classes of actions. Instead, they proposed that all these movements were mediated by one and the same underlying mechanism—perhaps the dorsal pathway.

Assuming that left-handed awkward grasping is indeed governed by ventral processes, our results are not consistent with the claim that Garner-Interference can distinguish between ventral and dorsal processing. Concerning this idea, a study conducted by Hesse and Schenk (2013) is of particular importance. They not only demonstrated that Garner-Interference in the perceptual speeded-classification task can be eliminated by varying the temporal profile of the response, but they were also able to elicit Garner-Interference in a grasping task by dissuading participants to make online corrections of the movement (but see Ganel & Goodale, 2003, supplementary material). As a consequence they argued that the dissociation found between the perceptual and the action task could be fully explained by the time available for response selection in the tasks, without needing to rely on the PAM.

Conclusions

The present study employed Garner-Interference to test whether two core assumptions of the PAM are compatible with each other: (a) certain actions (natural, highly practiced, and right-handed) are controlled by the dorsal vision for action pathway, while other actions (awkward, unpracticed, or left-handed) are controlled by the ventral vision for perception pathway (Gonzalez et al., 2006, 2008; Goodale 2008). (b) Only the dorsal vision for action pathway operates in an analytical fashion, being able to selectively focus on the task-relevant dimension of an object (Ganel & Goodale, 2003). Our study revealed a clear inconsistency within these two assumptions of the PAM. We found no Garner-Interference, neither in right-handed precision grasping nor in left-handed awkward grasping. We conclude therefore, that one or maybe both core assumptions of the PAM are faulty and are in need of reconsideration.

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References

Aglioti, S., DeSouza, J. F. X., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology, 5*(6), 679–685.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*(4), 433–436.

Bruno, N. (2001). When does action resist visual illusions? *Trends in Cognitive Sciences, 5*(9), 379–382.

Carey, D. P. (2001). Do action systems resist visual illusions? *Trends in Cognitive Sciences, 5*(3), 109–113.

Felfoldy, G. L. (1974). Repetition effects in choice reaction time to multidimensional stimuli. *Perception and Psychophysics, 15*(3), 453–459.

Franz, V. H. (2001). Action does not resist visual illusions. *Trends in Cognitive Sciences, 5*(11), 457–459.

Franz, V. H., & Gegenfurtner, K. (2008). Grasping visual illusions: consistent data and no dissociation. *Cognitive Neuropsychology, 25*(7), 920–950.

Franz, V. H., Gegenfurtner, K. R., Bülthoff, H. H., & Fahle, M. (2000). Grasping visual illusions: no evidence for a dissociation between perception and action. *Psychological Science, 11*(1), 20–25.

Franz, V. H., & Loftus, G. R. (2012). Standard errors and confidence intervals in within-subjects designs: generalizing Loftus and Masson (1994) and avoiding the biases of alternative accounts. *Psychonomic Bulletin & Review, 19*(3), 395–404.

Franz, V. H., Scharnowski, F., & Gegenfurtner, K. R. (2005). Illusion effects on grasping are temporally constant, not dynamic. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1359–1378.

Ganel, T., & Goodale, M. A. (2003). Visual control of action but not perception requires analytical processing of object shape. *Nature, 426*(6967), 664–667.

Garner, W. R. (1974). *The processing of information and structure*. Potomac: Erlbaum.

Garner, W. R. (1978). Selective attention to attributes and to stimuli. *Journal of Experimental Psychology: General, 107*(3), 287.

Gonzalez, C. L. R., Ganel, T., & Goodale, M. A. (2006). Hemispheric specialization for the visual control of action is independent of handedness. *Journal of Neurophysiology, 95*(6), 3496–3501.

Gonzalez, C. L., Ganel, T., Whitwell, R. L., Morrissey, B., & Goodale, M. A. (2008). Practice makes perfect, but only with the right hand: sensitivity to perceptual illusions with awkward grasps decreases with practice in the right but not the left hand. *Neuropsychologia, 46*(2), 624–631.

Goodale, M. A. (2008). Action without perception in human vision. *Cognitive Neuropsychology, 25*(7–8), 891–919.

Goodale, M. A., Meenan, J., Bülthoff, H., Nicolle, D., Murphy, K., & Racicot, C. (1994). Separate neural pathways for the visual analysis of object shape in perception and prehension. *Current Biology, 4*(7), 604–610.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20–25.

Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature, 349*(6305), 154–156.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95–112.

Haffenden, A. M., & Goodale, M. A. (1998). The effect of pictorial illusion on prehension and perception. *Journal of Cognitive Neuroscience, 10*(1), 122–136.

Hesse, C., De Grave, D. D. J., Franz, V. H., Brenner, E., & Smeets, J. B. J. (2008). Planning movements well in advance. *Cognitive Neuropsychology, 25*(7–8), 985–995.

Hesse, C., & Schenk, T. (2013). Findings from the Garner-paradigm do not support the ‘how’ versus ‘what’ distinction in the visual brain. *Behavioural Brain Research, 239*, 164–171.

James, T. W., Culham, J., Humphrey, G. K., Milner, A. D., & Goodale, M. A. (2003). Ventral occipital lesions impair object recognition but not object-directed grasping: a fMRI study. *Brain, 126*(11), 2463–2475.

Janczyk, M., Franz, V. H., & Kunde, W. (2010). Grasping for parsimony: do some motor actions escape dorsal processing? *Neuropsychologia, 48*(12), 3405–3415.

Janczyk, M., & Kunde, W. (2010). Does dorsal processing require central capacity? More evidence from the PRP paradigm. *Experimental Brain Research, 203*(1), 89–100.

Janczyk, M., & Kunde, W. (2012). Visual processing for action resists similarity of relevant and irrelevant object features. *Psychonomic Bulletin & Review, 19*(3), 412–417.

Janczyk, M., & Kunde, W. (2014). Garner-Interference in skilled right-handed grasping is possible (submitted).

Janczyk, M., Pfister, R., & Kunde, W. (2013). Mice move smoothly: irrelevant object variation affects perception, but not computer mouse action. *Experimental Brain Research, 231*(1), 97–106.

Jonas, M., Eloka, O., Stephan, J., & Franz, V. H. (2014). Need for space: the key distance effect depends on spatial stimulus configurations. *PLoS ONE, 9*(3), e91432.

Kunde, W., Landgraf, F., Paelecke, M., & Kiesel, A. (2007). Dorsal and ventral processing under dual-task conditions. *Psychological Science, 18*(2), 100–104.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin and Review, 1*(4), 476–490.

Milgram, P. (1987). A spectacle-mounted liquid-crystal tachistoscope. *Behavior Research Methods, Instruments, & Computers, 19*(5), 449–456.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spatial Vision, 10*(4), 437–442.

Posner, M. I. (1964). Information reduction in the analysis of sequential tasks. *Psychological Review, 71*(6), 491–504.

Schenk, T., Franz, V. H., & Bruno, N. (2011). Vision-for-perception and vision-for-action: which model is compatible with the available psychophysical and neuropsychological data? *Vision Research, 51*(8), 812–818.

Smeets, J. B. J., & Brenner, E. (2006). 10 years of illusions. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1501–1504.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549–586). Cambridge, MA: MIT Press.

Westwood, D. A., & Goodale, M. A. (2011). Converging evidence for diverging pathways: neuropsychology and psychophysics tell the same story. *Vision Research, 51*(8), 804–811.