Grasping and perception are both affected by irrelevant information and secondary tasks: New evidence from the Garner paradigm

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Abstract

In their Perception-Action Model (PAM), Goodale and Milner (1992) proposed functionally independent and encapsulated processing of visual information for action and perception. In this context, they postulated that visual input for action is processed in an automatized and analytic manner, which renders visuomotor behaviour immune to perceptual interferences or multitasking costs due to sharing of cognitive resources. Here, we investigate the well-known Garner Interference effect under dual- and single-task conditions in its classic perceptual form as well as in grasping. Garner Interference arises when stimuli are classified along a relevant dimension (e.g., their length), while another irrelevant dimension (e.g., their width) has to be ignored. In the present study, participants were presented with differently sized rectangular objects and either grasped them or classified them as long or short via button-presses. We found classical Garner Interference effects in perception as expressed in prolonged reaction times when variations occurred also in the irrelevant object dimension. While reaction times during grasping were not susceptible to Garner Interference, effects were observed in a number of measures that reflect grasping accuracy (i.e., poorer adjustment of grip aperture to object size, prolonged adjustment times, and increased variability of the maximum hand opening when irrelevant object dimensions were varied). In addition, multitasking costs occurred in both perception and action tasks. Thus, our findings challenge the assumption of automaticity in visuomotor behaviour as proposed by the PAM.

1 Introduction

According to the Perception-Action Model (PAM), the visual system in the primate brain is subdivided into two anatomically and functionally distinct streams (Goodale & Milner, 1992; Milner & Goodale, 1995, 2006). The dorsal stream, extending from the primary visual cortex (V1) to the parietal cortex, is assumed to serve the goal of processing visual information for action, while the ventral stream runs from V1 into the inferior-temporal cortex and is thought to primarily process visual information for perception. According to the PAM, the two streams constitute separate and independent visual systems.

Over the last decades, this very influential model has been criticized (Schenk, 2006, 2012; Schenk, Franz, & Bruno, 2011; Schenk & Hesse, 2018) and many studies originially providing supporting evidence for segregated neurological pathways for perception and action processing (e.g., Aglioti, DeSouza, & Goodale, 1995; Ganel, Chajut, & Algom, 2008; Ganel & Goodale, 2003, 2014; Goodale et al., 1994; Goodale & Milner, 1992) have been challenged (e.g., see Kopiske, Bruno, Hesse, Schenk, & Franz, 2016 for illusions, and Schenk et al., 2017; Utz, Hesse, Aschenneller, & Schenk, 2015 for Weber's law). However, there are two lines of evidence that have received comparably little scrutiny until now: The Garner Interference effect (Ganel & Goodale, 2003, 2014) and dual-task studies (Liu, Chua, & Enns, 2008; Singhal, Culham, Chinellato, & Goodale, 2007). We designed the current study with the aim to re-examine the evidence presented in favour of the PAM from these two behavioural paradigms. In the following, we will briefly summarise the existing literature, deduce the open questions in these fields, and explain the potential advantage of combining research on Garner Interference with research on dual-tasking.

1.1 Garner Interference

Garner Interference is an interesting phenomenon from the field of cognitive psychology (Garner, 1976, 1978). The key of this paradigm is that stimuli are created in such a way, that they either vary only along a relevant dimension (i.e., the dimension participants are asked to judge) or vary along two dimensions: a relevant and an irrelevant one. Reaction times (RT) are determined separately in blocks in which only the relevant dimension is varied (i.e., baseline blocks) and in blocks in which stimuli vary along both the relevant and the irrelevant dimension (i.e., filter blocks). Depending on the properties that are varied, interference effects occur when variations are present also in an irrelevant dimension of the target as indicated by slower reaction times (RTs) in the filter blocks as compared to the baseline blocks. For example, participants are usually faster to indicate the width of a rectangle (narrow vs. wide) if its length is kept constant or vice versa. If, however, the presented rectangles vary in both dimensions, the RTs for indicating target width increase considerably. This observation has led to the suggestion that the length and width of an object are integral dimensions that cannot be processed independently by the perceptual system. In contrast, other dimensions such as a target's width and its colour were not found to show this kind of interference and can hence be considered to be (perceptually) separable dimensions (Garner, 1976).

Ganel and colleagues applied this paradigm to the domain of visuomotor research (Ganel & Goodale, 2003, 2014). On the basis of the PAM they reasoned that the visuomotor system processes visual information differently. Specifically it was assumed that the visuomotor system focuses on the action-relevant dimension of an object and ignores variations in the action-irrelevant dimensions (analytic processing style). In the case of grasping, the action-relevant dimension might be the length of the object and thus variations in its width should have no effect on the timing or accuracy of the grasping movement. As predicted, Ganel and Goodale (2003) found Garner Interference in a perceptual width-discrimination task but not in the corresponding grasping task. They argued that these findings demonstrate that the perception and the action system process visual information fundamentally differently (holistic vs. analytic processing style), a distinction which was also supported by a more recent study (Janczyk & Kunde, 2012).

However, Hesse and Schenk (2013) proposed that the observed dissociation between perception and action may have resulted from discrepancies in the temporal profile of the two response types (button presses versus grasping). More specifically they suggested that the relatively small Garner Interference effects (20-30 ms) can only be detected in tasks where strict time constraints are imposed. In speeded perceptual judgements, time constraints are introduced by instructing participants to respond as rapidly as possible resulting in relatively short RTs of around 350 to 450 ms. In contrast, when grasping objects, the time to make a decision is distributed across different phases: the time before the movement is initiated and the time during which the movement is executed. Hence, RTs are likely to be unsuitable to determine interference effects in actions given that the decision about the relevant object dimension may not yet be over by the time the movement is initiated. In other words, the decision time available in the grasping task is usually much longer than in a corresponding perceptual task as the overall time available to make the decision is composed of the time before and the time during the movement. Thus, the time constraints imposed during grasping may be too liberal to provide sufficient sensitivity to detect the relatively small Garner Interference effects. Consequently, Hesse and Schenk (2013) predicted that if time constraints for the perceptual judgement task and the grasping task are equalised, the dissociation disappears. In line with this prediction, they found that when decision times were increased in the perceptual task, Garner Interference disappeared. Conversely, when stricter constraints were imposed during the grasping task, Garner Interference was also evident in visuomotor measures (Hesse & Schenk, 2013).

Further indirect evidence for the suggestion that RTs might be an insensitive measure to reveal Garner Interference in tasks with more liberal time constraints comes from studies that investigated Garner Interference in action tasks that supposedly rely on ventral stream processing (Eloka, Feuerhake, Janczyk, & Franz, 2015; Janczyk, Franz, & Kunde, 2010). According to the PAM, unskilled movements are reliant on ventral stream processing and should hence be affected by irrelevant object features. However, studies testing left-handed and awkward grasping as well as grasping with a pair of pliers (Janczyk et al., 2010; Eloka et al., 2015) were unable to detect Garner Interference in these tasks further challenging the idea that only skilled and automatized grasping mediated by the dorsal stream is immune to variations in irrelevant object features. Furthermore, more recently, Janczyk and Kunde (2016) observed Garner Interference in both a perceptual and a grasping task when employing a weight manipulation as an irrelevant object manipulation indicating that changes in irrelevant object features other than target size can affect visuomotor measures.

In sum, these findings illustrate that the classical Garner task of measuring RTs while varying object shape may be problematic when comparing Garner Interference effects between perception and action tasks. One way to account for the asymmetry between perception and action tasks would be to use more sensitive temporal measures or to focus on movement accuracy rather than timing. Ganel and Goodale (2014) adopted the latter approach in a recent study. Specifically, they compared the variability of the maximum grip aperture (MGA) during a grasping task (visuomotor condition) with the variability of the hand aperture when participants were asked to pantomime the grasp (perceptual condition). They found Garner Interference, as indicated by an increase in MGA variability in the filter conditions relative to the baseline conditions in the pantomime condition, but not in real grasping. While this is an interesting finding, we feel that there are other (more common) measures of grasping accuracy that should be taken into consideration before making any final conclusions.

A more established and commonly reported measure of grasping accuracy is the slope of the function relating object size to MGA. It is well known that MGA is linearly related to object size and the slope of that linear function expresses the sensitivity with which the grasping hand adjusts to the relevant dimension of the target object (Hesse & Franz, 2009b; Smeets & Brenner, 1999). Moreover, while RT may be an insensitive measure, other temporal measures could potentially be more informative. Specifically, this requires finding a measure that indicates the perceptual decision time in grasping more reliably than RT. During the course of the movement the grip is continuously adapted to the size of the target object and differences in the size of the aperture can already be observed well before MGA is reached (Jeannerod, 1984). Thus, the moment the hand-opening reliably diverges for grasping smaller and larger objects can be considered as an early indicator that participants are taking into account object size. Here we employ such an early adjustment measure and predict that, if Garner Interference affects grasping, adjustment times should be delayed in the filter condition as compared to the baseline condition.

1.2 Dual-Tasking

The PAM's assumption of dorsal stream automaticity has been addressed using dual-task paradigms (e.g., Liu et al., 2008; Singhal et al., 2007). With respect to dual-tasking, the PAM predicts that dorsal visuomotor processes do not depend on central cognitive resources and should thus not be affected by concurrent demands of other independent (e.g., perceptual or cognitive) tasks. Typically, dual-task costs are demonstrated by deterioration of the performance (such as prolonged RTs and decreased accuracy) in one or both tasks when they are executed concurrently as compared to separately (Pashler, 1989, 1994). Liu and colleagues (2008) were one of the first authors who suggested that visuomotor tasks may be exempt from these dual-tasking costs. They combined a pointing task and a rapid serial visual presentation (RSVP) task and found no difference in movement times between single- and dual-task conditions, but prolonged movement initiation times (i.e., RTs) in dual-task conditions as compared to single-task conditions. They concluded that only action planning which is supposedly mediated by the ventral stream is affected by a secondary task. In contrast, action programming that is assumed to be mediated by the dorsal stream showed no dual-task costs. However, there is a conceptual problem regarding this interpretation and the underlying definition of action programming. The choice to perform a grasping action is a planning act, but the process of adjusting the grasping movement to the location and the size of the target object during the RT-interval is part of the programming process (see Milner & Goodale, 1995; 2008 but also Schenk, 2010 for a more detailed discussion of the distinction between action planning and action programming). Consequently, differences in RT should be considered indicative of movement programming being affected by dual-task requirements. The dissociation between dual-tasking costs for offline (as reflected in RTs) but not online adjustments (as reflected in MTs) as observed by Liu and colleagues can however not easily be mapped onto the distinction between ventral and dorsal processing. Interestingly, in line with this argument, another study that examined dual-task interference in a visuomotor task using a Psychological Refractory Period (PRP) paradigm found increased RTs in the presence of a secondary task (Kunde, Landgraf, Paelecke, & Kiesel, 2007). Kunde and colleagues (2007) interpreted this finding as evidence against the PAM. In particular, the authors argued that responses based on dorsal and ventral processing were both affected similarly by strains on central resources (see also, Janczyk & Kunde, 2010).

Finally, it is important to note that Liu et al. (2008) were only able to measure the overall duration and the end-position of the movement as they employed a touch screen monitor and did not measure participants' movement kinematics. Thus, any online changes would have been missed. This is particularly problematic as subsequent studies that measured hand movements continuously, suggested that dual-task costs become primarily apparent during the earlier parts of the movement (Hesse & Deubel, 2011; Hesse, Schenk, & Deubel, 2012) or when quick online corrections are required (Sandoval Similä & McIntosh, 2015).

However, there is also evidence for the suggestion that dorsal stream processing is immune to dual-task costs from a study employing a delayed action paradigm (Singhal et al., 2007). Specifically, this study exploited the fact that actions towards memorised targets (delayed actions) are supposed to be guided by the ventral stream while non-delayed or immediate actions are presumed to be served by the dorsal stream (e.g., Hu, Eagleson, & Goodale, 1999; Culham et al., 2003). In line with this argument, Singhal et al. (2007) found larger dual-task interference effects in the delayed action task (ventral processing) than in the visually guided grasping task (dorsal processing) providing further support for the assumption that the dorsal stream may be immune to cognitive interference. Yet, the findings are, in our opinion, not conclusive. Firstly, many recent studies have questioned the underlying assumption that delayed and non-delayed actions are served by distinct visual streams (for a review, see Schenk & Hesse, 2018). Secondly, the timing of the secondary task was problematic as it was presented at the moment the visual target information was withdrawn in the delayed condition. Thus, at the very time participants realised they will have to memorise the target object, they were also given a second cognitive task to solve. This could explain why interference was enhanced during these delayed-action tasks. Finally, even though the dual-task interferences tended to be larger in the delayed action task, there were still (smaller) interference effects during visually guided grasping with MGAs being larger and MTs being longer in dual-task conditions as compared to single-task conditions.

In summary, we would argue that there is currently no convincing evidence for the idea that dorsal stream tasks are immune to cognitive interference as claimed by the PAM. Instead dual-task costs have been found reliably in the visuomotor domain, in particular in studies employing PRP paradigms (Janczyk & Kunde, 2010; Kunde et al., 2007). With respect to dual-tasking, the aim of the current study was to further clarify whether or not dual-task effects occur reliably in visuomotor tasks also in situations in which the primary and secondary task are executed simultaneously and whether the effects are mediated by the nature of the secondary task.

1.3 Combining Garner Interference with Dual-Tasking

In addition to testing the mere existence of dual-task interference effects during grasping, we were interested in whether, and to which extent, interference between a primary action task and a secondary visuo-attentional or cognitive task may depend on the similarity of the two tasks. Most importantly, we hypothesise that a combination of both paradigms could potentially amplify the effects of Garner Interference and dual-tasking and thus produce more reliable findings. The reasoning for this assumption is simple. If we assume that actions are susceptible to Garner Interference and dual-task costs, both effects may enhance each other. Specifically, the addition of a secondary task might slow down the perceptual decision process and thereby increase the temporal difference between a simple (Garner-baseline condition) versus a complex (Garner-filter condition) decision making process. The result would be a more pronounced Garner effect in dual-tasking conditions as compared to single-task conditions. In other words, by combining both paradigms, one might potentially make the Garner Interference more detectable. Moreover, by using a dual-tasking approach in which the similarity between the primary task and secondary task is manipulated, we can also test if increasing the saliency of distracting information present in the primary task further increases the Garner Interference effect. In other words, if the secondary task requires participants to attend to object shape (rather than colour) one might not only expect larger dual-task costs in general but also an increased Garner Interference effect in particular.

In summary, we combine the classic perceptual Garner paradigm (judgement of object length) as well as its visuomotor version (grasping objects along their length) with a secondary visuo-attentional task in order to address three questions: (1) Do irrelevant features, as reflected in Garner Interferences, affect perception as well as action? Importantly, we will employ novel measures which, for reasons detailed above, are in our view more appropriate to look for Garner effects in visuomotor tasks. (2) Do dual-task costs depend on the similarity between the primary task (i.e., Garner task) and the secondary task? (3) Does a dual-task context enhance the impact of irrelevant features on a primary perceptual or visuomotor task (i.e., increase the Garner Interference)? We hypothesise that by combining the two tasks we can boost the usually small Garner Interference effects leading to more reliable findings that can potentially settle the question of whether or not actions are immune to stimulus variations in action-irrelevant dimensions.

2 Methods

2.1 Participants

Forty-four (10 males) neurologically healthy undergraduate and postgraduate students and staff members of the University of Aberdeen (UK, Scotland) participated in the study. The data set of one participant, who was unable to perform the task, was excluded from analysis. The age of the remaining participants ranged from 18 to 40 years with a mean age of 23 years (standard deviation of 5 years). Participants were assigned to two conditions with one group (N=24) performing the perceptual task and one group (N=24) performing the grasping task. Five participants completed both the grasping task and the perceptual task. Participants received either course credits or were paid for their participation (£5/hour). All participants were right-handed by self-report, had no neurological or motor impairments and normal or corrected-to-normal visual acuity as well as normal colour vision. Prior to the study, all participants provided informed consent, and the protocol was approved by the Psychology Research Ethics Committee, University of Aberdeen (PEC/3589/2016/12).

2.2 Set-up

A mirror set-up was used for stimulus presentation in both the perceptual and the grasping task. A computer monitor (EIZO Foris FG2421, 23.5”, refresh rate 60 Hz, 1920 x 1080 pixel) was attached to a metal frame with the screen facing downwards. The screen of the monitor reflected onto a semi-transparent mirror (56 cm x 40 cm) positioned at a distance of 34 cm. A wooden board was placed 34 cm beneath the mirror and served as presentation surface for the stimuli. Visual stimuli presented on the screen were reflected by the mirror and consequently perceived by the participant as being placed on the presentation surface. As the compartment above the mirror was lit up by the screen, both the real object present in the grasping task as well as participants’ hands remained invisible underneath the mirror. A small felt pad with a diameter of 5 mm was attached to the presentation board and served as the start position of the hand in the grasping task. The distance between the starting position and the midpoint of the grasping object was 24 cm. In the perceptual task, a two-button response box was placed at this location (for details see procedure). Participants sat in a comfortable position in front of the mirror setup on a height-adjustable chair with their head resting on a chinrest looking directly onto the mirror. Prior to the start of the experiment, we calibrated the mirror-setup to compensate for possible visual distortion caused by slight variations in viewing angle. Specifically, we adjusted the presentation location of the virtual stimuli in the grasping task so that they were perceived by participants as overlapping with the real object (this was achieved by switching on lights in the lower compartment of the mirror set-up such that both the real and the virtual stimulus were visible during calibration).

To record hand movements in the grasping task, an infra-red based Optotrak 3020 motion registration system (Northern Digital Incorporation, Waterloo, Ontario, Canada) was used at a sampling rate of 200 Hz. Before starting the measurement, we calibrated the Optotrak system such that the Cartesian coordinate system was aligned to the presentation surface located underneath the mirror. We attached two IREDs on the nails of each participant's right index finger and thumb. The experiment was programmed in Matlab (The MathWorks Inc., Natick, Massachusetts, United States) using the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007) and the Optotrak Toolbox (Franz, 2004).

2.3 Stimuli and Procedure

In both the grasping and the perceptual task there were two main experimental variations: the Garner component and the dual-tasking component. Regarding the dual-tasking component, we tested three different conditions (in the following referred to as "dual-tasking conditions" although one of them is in fact a single-task condition): 1) a single-task condition with no secondary task (control condition), 2) a dual-task condition where the secondary task was related to the primary task (i.e., detecting a target stimulus of a certain shape within an RSVP) and 3) a dual-task condition in which the secondary task was unrelated to the primary task (i.e., detecting a target stimulus of a certain colour in an RSVP task). Within each of the three dual-tasking conditions, we introduced a Garner task (primary task) consisting of experimental blocks in which objects varied either only along the relevant dimension (baseline blocks) or in which they varied along both the relevant and an irrelevant dimension (filter blocks). We will first describe the Garner task in more detail (section 2.3.1) and then specify the different dual-tasking conditions (section 2.3.2).

2.3.1 Garner Task

All trials, independent of the current experimental condition, started with a white central fixation cross presented on a black background. After 500 ms, the fixation cross was replaced by one of four differently sized white rectangles. Four different rectangles were created by combining 2 different lengths (40 mm and 60 mm) with two different widths (20 mm and 30 mm), i.e., W20-L40, W20-L60, W30-L40 and W30-L60 mm (see Figure 1). In the baseline blocks, we presented two of the rectangles that varied in the length dimension only while their width remained constant across trials. Hence, both the objects with a width of 20 mm were presented in one of the baseline blocks and both objects with a width of 30 mm in another separate baseline block. Within each baseline block, both rectangles were presented 12 times each (24 trials per block). In filter blocks, all four rectangle shapes were presented meaning that both dimensions (width and length) could change from trial to trial. Every one of the four rectangles was presented 6 times resulting in 24 trials per block. To match the numbers of presentations of each rectangle shape between baseline and filter blocks, there were two filter blocks in total (i.e., 12 presentations per rectangle size). For all participants filter and baseline blocks were presented interleaved (see section 2.3.3 on counterbalancing for more information).

In the *perceptual task*, participants were asked to respond to the rectangle's length and to indicate as fast as possible, using a left or right button-press on the response box, whether the presented rectangle was short (40 mm) or long (60 mm). In filter conditions, they were instructed to ignore the variations in width. The rectangle disappeared one second after a button-press was registered. Half of the participants in the perceptual task used the left index finger for indicating 'long' and the right index finger for indicating 'short' classifications, while the other half had the opposite assignment.

In the *grasping task*, participants were instructed to grasp a wooden block presented beneath the mirror (matching the virtual presentation of the rectangle in shape) along its length dimension as soon as the virtual object appeared on the screen. Before each grasping trial, the experimenter placed the wooden target object under the mirror at the central position corresponding to the position of the visual stimulus. Each object was positioned accurately on the presentation surface under the mirror with a little pin fitting a matching cut-out in the board. Hence, participants grasped for the virtual stimulus and encountered a real 3D object (thickness of 20 mm) at its position. The virtual object was removed from the screen upon movement onset, which was defined as the moment at which the Euclidean distance between the start position and one of the finger markers exceeded 25 mm. Due to the lighting conditions, participants were unable to see their hand and the real object during grasping (open-loop condition). The experimenter started each trial manually by pressing a key and participants grasped and lifted the object with a precision grip using index finger and thumb. Participants had 2 seconds to complete their movements after the presentation of the stimulus.

2.3.2 Secondary Tasks

Simultaneously with the Garner task, participants performed one out of two different visual secondary tasks (in addition to a control condition in which no secondary task was employed). Hence the Garner task described in the previous paragraph was completed in three different secondary task conditions: 1) no secondary task (control condition), 2) Garner-relevant secondary task (shape condition) and 3) Garner-irrelevant secondary task (colour condition).

Both secondary tasks were RSVP tasks with the goal of detecting a pre-defined target stimulus. RSVP stimuli were presented on the left side of the mirror, next to the white rectangle relevant for the Garner task. The exact position of the stream of RSVP stimuli was varied randomly between trials either occurring 150 pixels or 300 pixels to the left of the centrally presented Garner stimulus. This spatial variation was introduced in order to prevent participants from adopting facilitating strategies for target detection and to induce a jitter for more generalizable results. The presentation duration of each stimulus within the RSVP was ~50 ms (i.e., 3 frames at 60 Hz monitor refresh rate) and the inter-stimulus blank interval of ~85 ms (i.e., 5 frames at 60 Hz monitor refresh rate). At the beginning of each trial, the program determined randomly whether or not the target stimulus appeared. The target stimulus was defined by its colour in the Garner-irrelevant secondary task and by its shape in the Garner-relevant secondary task. The target could occur at any time during the trial. At the end of each dual-task trial, participants reported verbally whether or not they had seen the target stimulus (two alternative forced choice task), and the experimenter entered their response into the program. Stimuli for the Garner-irrelevant colour task were squares (50 mm x 50 mm) coloured in various shades of purple, which we generated by changing the blue-component within the RGB system. The RGB values for the four distractors were set to [125 50 255], [125 50 102], [125 50 153] and [125 50 204]. The target was perceived as being slightly more orange than the other stimuli (RGB value: [125

50 20]). In the Garner-relevant shape task, distractor stimuli were the same four white rectangles that we used for the Garner task, while the target stimulus was a smaller white square (25 mm x 25 mm). Task difficulty was piloted on N=5 to achieve accuracy rates of about 85% in a single-task condition. In both dual-task conditions, the RSVP tasks started simultaneously with the appearance of the rectangle for the Garner task and lasted for 2s. Participants were instructed to keep fixation during the trial at the central Garner rectangle and to view the RSVP task in visual periphery.

2.3.3 Randomisation and Counterbalancing

In both, the grasping task and the perceptual task, the dual-tasking condition component (control, shape and colour) was blocked and counterbalanced across participants (i.e., 6 possible dual-tasking block orders counterbalanced across N=24 participants in each task). Within each of these dual-tasking blocks participants performed 96 trials of the Garner task which were divided in 4 sub-blocks of two baseline and two filter conditions (consisting of 24 trials each). Baseline and filter conditions were presented in an alternating fashion resulting in four different possible arrangements (B1F1B2F2, B2F2B1F1, F1B1F2B2 or F2B2F1B1). These four arrangements were counterbalanced across participants and dual-tasking blocks. Finally, within each filter and baseline block, stimuli were presented in a randomised fashion and the occurrence of the RSVP target was determined randomly for each trial in the dual-tasking conditions.

2.4 Data Analysis

Data processing and analysis were performed using the commercial software packages MATLAB R2015a (The MathWorks Inc., Natick, Massachusetts, United States) and SPSS (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.).

Grasping Data: Movement data from the IRED markers were filtered offline using a second-order Butterworth filter with a low-pass cut-off frequency of 15 Hz. We were interested in several parameters including reaction time (RT), movement time (MT) and maximum grip aperture (MGA). Movement onset was defined as the first frame in which one of the markers attached to thumb and index finger exceeded a velocity threshold of 0.05 m/s. RT was defined as the time between stimulus onset and movement onset. The end of the movement was reached when the resultant velocity of one of the markers attached to thumb and index finger dropped below a velocity threshold of 0.075 m/s. MT was defined as the time between movement onset and end of the movement. The grip aperture was calculated as the 3D distance between thumb and index marker. The maximum of this distance between movement onset and end of the movement was defined as the MGA. Trials with substantial data loss, especially around the time of the MGA, or with RTs below 100 ms were discarded offline (2.8 % of all trials).

Perceptual Data: In the perceptual task, we measured RTs as the time interval between stimulus onset and the registered button-press.

For all timing data (i.e., RTs and MTs) we calculated the median time for each condition and participant. We used medians instead of means for our analyses of timing variables in order to enhance robustness against outliers. Note that the qualitative pattern of results remains identical when using means. For the accuracy data (i.e., MGA), we calculated the arithmetic mean and determined the standard deviation for each condition and participant as a measure of variability. Furthermore, we determined the slope of the function relating MGA to object size using linear regression analysis for each participant and condition separately. This measure is commonly used in the literature to determine how well participants adjusted their hand opening to the target size in the grasping task (Freud, Ganel, Avidan, & Gilaie-Dotan, 2016; Hesse & Franz, 2009b; Hesse et al., 2012). Moreover, we also calculated an additional aperture adjustment measure reflecting the point in time by which participants had reliably adjusted their grip apertures to the respective object length. To do so, we computed for every participant and each object length the mean aperture profile for each Garner and dual-tasking condition starting at movement onset and averaging each sample in real-time (every 5 ms) over the course of the movement. Subsequently, we determined the point in time at which the mean aperture size for long objects diverged from the mean aperture size of short objects by at least half the object size difference (i.e., 10 mm) (see Hesse & Franz, 2009a for a similar procedure).

All data were statistically analysed using 2 (Garner condition: baseline vs. filter) x 3 (dual-task condition: control, dual-task colour, dual-task shape) repeated-measures ANOVAs. If the sphericity assumption was violated, p-values were Greenhouse-Geisser corrected (full degrees of freedom are reported with corresponding ε-values). Post-hoc comparisons were corrected for multiple testing using the Bonferroni method and a significance threshold of $\alpha = .05$ was used to determine statistical significance. The datasets analysed during the current study are available at zenodo.org, doi: 10.5281/zenodo.1408787.

3 Results

3.1 Perceptual Task

Figure 2 depicts the median RTs averaged across all participants in baseline and filter tasks for each of the three dual-tasking conditions. The 2 x 3 repeated-measures ANOVA revealed highly significant main effect of Garner condition $F(1,23) = 48.23$, $p < .001$, $\eta_p^2 = .677$, showing that participants were consistently slower to indicate the rectangles' length in the filter condition than in the baseline condition. On average the Garner Interference effect was about 32 ± 5 ms which is similar to that observed in previous studies (Ganel & Goodale, 2003, 2014; Garner, 1976; Hesse & Schenk, 2013). Furthermore, we found a highly significant main effect of dual-tasking condition, $F(2,46) = 178.47$, $p < .001$, $\eta_p^2 = .886$. Pairwise comparisons revealed that participants were significantly faster in the control condition (395 ± 9 ms) as compared to both dual-task conditions (colour: 595 ± 15 ms and shape: 606 ± 17 ms, both $p < .001$). RTs in both dual-task conditions did not differ significantly from each other ($p > .999$). These results indicate that there were, as expected, large dual-tasking costs as a consequence of sharing cognitive capacities between two simultaneous perceptual tasks (Pashler, 1989, 1994). Finally, there was no significant interaction effect, $F(2,46) = 0.20$, $p = .980$, $\eta_p^2 = .001$, suggesting that the Garner Interference effect was not modulated by dual-tasking constraints. The absence of an interaction effect is in conflict with our hypotheses, since we expected the size of the Garner Interference effect to be modulated by the secondary task. Specifically, we expected that the Garner Interference may increase when the task requirements of the secondary task are similar to those of the primary Garner task (i.e., in the dual-task shape condition). Clearly this was not the case in our data.

3.2 Grasping Task

3.2.1 Timing of the movement: RT, MT and Adjustment times

Figure 3 shows RT data from the grasping task. The analysis revealed no main effect of Garner condition, $F(1,23) = 0.16$, $p = .694$, $\eta_p^2 = .007$, suggesting that participants were equally quick to initiate their grasping movements in baseline and filter conditions. However, there was a significant main effect of dual-tasking condition, $F(2,46) = 7.67$, $p = .001$, $\eta_p^2 = .250$. As in the perceptual experiment, post-hoc comparisons revealed reliable dual-task costs for movement initiation times: RTs in the control condition (239 ± 8 ms) were significantly quicker than in both dual-task conditions (colour: 261 ± 8 ms, $p = .011$, shape: 263 ± 5 ms, $p = .006$), while there was no difference between the two dual-task conditions ($p > .999$). This finding suggests that there is dual-task interference in grasping, affecting the grasp planning process. There was no interaction effect between the Garner and the dual-tasking conditions, $F(2,46) =0 .41$, $\varepsilon = .761$, $p = .612$, $\eta_p^2 = .017$.

Concerning the MTs, our analyses did neither yield an effect of Garner condition, $F(1,23) = 0.56$, $p = .461$, $\eta_p^2 = .024$, nor an interaction effect between Garner and dual-tasking condition, $F(2,46) = 1.10$, $p = .343$, $\eta_p^2 = .045$. There was also no significant main effect of dual-tasking condition, $F(2,46) = 1.90$, $\varepsilon = .782$, $p = .172$, $\eta_p^2 = .076$. Descriptively MTs were longest in the dual-task shape condition (527 ± 20 ms) and shortest in the single-task condition (496 ± 18 ms), with MTs in the dual-task colour condition falling roughly in-between (510 ± 16 ms). Thus, descriptively MTs slightly increased with enhanced similarity between the primary and the secondary task (i.e., dual-task shape condition), but this effect was not statistically significant.

The adjustment times are depicted in Figure 4. Interestingly, the 2 x 3 repeated measures-ANOVA revealed a significant main effect of the Garner condition, $F(1,23) = 5.39$, $p = .029$, $\eta_p^2 = .190$, with a later adjustment of the hand opening to object length in the filter (340 ± 27 ms) as compared to the baseline conditions (305 ± 22 ms), as well as a significant main effect of dual-tasking condition, $F(2,46) = 4.51$, $p = .016$, $\eta_p^2 = .164$. Post-hoc tests showed that the adjustment of the aperture occurred significantly later in the dual-task shape condition (357 ± 27 ms) than in both, the control condition (302 ± 27 ms, $p = .045$) and the dual-task colour condition (308 ± 23 ms, $p = .022$) which did not differ significantly from each other ($p > .999$). There was no significant interaction effect, $F(2,46) = 0.39$, $p = .681$, $\eta_p^2 = .017$. In summary, this measure specifically addressing the temporal adjustment of the grip aperture profile, illustrates a Garner Interference effect as well as dual-task costs. Importantly, dual-task costs were more pronounced when there was a higher similarity between the primary and secondary task demands (i.e., shape condition). Note that this delayed adjustment in the shape condition was not reflected in an overall increase in MTs.

At a first glance, it might appear that the missing Garner Interference effect in RT and MT, representing two of the main timing measures of the grasp, supports the view that the action system processes information analytically and thus differently to the perceptual system whereby providing evidence for a functional dissociation between the two processes as suggested by Ganel and Goodale (2003). However, as argued in the introduction and also previously by Hesse and Schenk (2013), commonly used timing measures such as RT and MT might not be the most reliable variables to uncover Garner Interference effects in grasping. Remarkably, a timing measure that is more specifically tailored to reflect decision making during the grasping movement – i.e., the early adjustment times of the grip to object size - did show Garner Interference. Note that Ganel and Goodale (2014) put forward a similar argument based on which they suggested that MGA variability might be a more suitable and robust measure than RT to reveal Garner Interference effects in action processes.

3.2.2 Accuracy of the movement: Variability of MGA and slopes

As it has been suggested that Garner Interference during grasping might reveal itself primarily in measures of movement accuracy rather than the timing of the movement, we also analysed MGA variability in line with a recent study by Ganel and Goodale (2014). Interestingly, and in contrast to the findings by Ganel and Goodale (2014), the 2 x 3 repeated-measures ANOVA on the data revealed a highly significant effect of Garner condition $F(1,23) = 18.90$, $p < .001$, $\eta_p^2 = .451$, with a larger variability of the MGA in filter conditions (6.02 ± .28 mm) than in baseline conditions (5.38 ± .28 mm). There was no main effect of dual-tasking condition, $F(2,46) = 0.76$, $p = .472$, $\eta_p^2 = .032$, and no interaction effect, $F(2,46) = 2.49$, $p = .094$, $\eta_p^2 = .098$. Interestingly, even though we did not find a significant interaction effect, and thus evidence for the idea that a Garner-related secondary task (shape task) enhances Garner Interference effects, the interference effects were at least descriptively much larger in the dual-task shape condition than in the single-task and dual-task colour conditions (see Figure 5) .

Previous research has established the linear relationship between MGA and object size as a reliable measure for how well participants adjust their hand opening to the object when grasping it (Freud et al., 2016; Goodale et al., 1991; Hesse & Franz, 2009b; Hesse et al., 2012; Karnath, Ruter, Mandler, & Himmelbach, 2009; Westwood, Danckert, Servos, & Goodale, 2002). MGA has been shown to be linearly related to object size over a wide variety of object sizes (Hesse & Franz, 2009b). Thus, the slope of the function relating MGA to object size is considered a robust indicator of the overall accuracy of the grip. Here, we used these slopes as an additional accuracy measure to determine the occurrence of the Garner Interference effect during grasping. Specifically, we hypothesised that if the action system takes into account a secondary (grasp-irrelevant) dimension then the grip calibration to the grasp relevant dimension should be slightly impaired in the filter conditions. Indeed, the 2 x 3 repeated-measures ANOVA on the slopes revealed again a highly significant main effect of Garner condition, $F(1,23) = 10.28$, $p = .004$, $\eta_p^2 = .309$. As we hypothesised, slopes were shallower in the filter (.56 ± .049) than in the baseline condition (.62 ± .046), demonstrating a decreased accuracy in adapting the hand opening to object size (see Figure 6). Furthermore, there was also a main effect of dual-tasking condition, $F(2,46) = 3.78$, $p = .030$, $\eta_p^2 = .141$. Post-hoc comparisons showed that slopes were significantly steeper in the control condition (.62 ± .053) than in the dual-task shape condition (.55 ± .047, $p = .018$) while there was no difference between the control condition and the dual-task colour condition (.61 ± .047, $p > .999$) and also no significant difference between the two dual-task conditions ($p = .170$). The interaction between both factors was again not significant, $F(2,46) = 0.20$, $\varepsilon = .796$, $p = .770$, $\eta_p^2 = .009$. The finding further highlights that action execution is susceptible to dual-task interference effects in particular in situations where properties of the perceptual secondary task are also relevant for the primary visuomotor task (i.e., shape of the stimulus).

4 Discussion

4.1 Garner Interference

The first question we aimed to address in this study was whether or not visuomotor tasks that require dorsal stream processing such as grasping are immune to Garner Interference. Our findings clearly indicate that this is not the case. We found evidence of significant Garner Interference in three out of five measures of grasping. Garner Interference increased the variability of the MGA, reduced the sensitivity with which the hand opening adjusted to the size of the target object (MGA slope), and delayed the time at which the hand aperture reliably reflected the length of the target object (adjustment time). Similar as previous studies, we did not find reliable interference effects in RT and MT (e.g., Ganel & Goodale, 2003, 2014).

It seems surprising that we found a clear Garner Interference effect on MGA variability while Ganel and Goodale (2014) did not. However, based on our findings we are able to offer a possible explanation for this discrepancy: At least descriptively, Garner Interference affecting MGA variability was clearest in dual-task shape conditions in our study. As we had hypothesised, this additional task might have slightly enhanced the Garner Interference effect and thus may have made it easier for us to detect the relatively small effects (see section 4.3). Without inclusion of the dual-task shape condition it is questionable if the effect would have reached significance (see Figure 5). Furthermore, in addition to using a single-task condition only, Ganel and Goodale (2003, 2014) ran their experiments under closed-loop vision conditions, providing participants with a better opportunity to adapt their hand during the grasping movement.

One reviewer pointed out that a potential alternative explanation for an increase in MGA variability when the Garner effect is tested in the dual-task conditions may be that participants might have not followed our instructions of looking at the Garner target but may instead have looked at the RSVP stimuli. In this case the Garner target would have appeared in their in visual periphery, resulting in reduced visual accuracy and thereby potentially enhancing MGA variability. However, previous studies investigating grasping to targets presented in the observer's visual periphery found that the size of MGA tends to increase with increasing visual eccentricity, but both MGA-variability and grip scaling remain stable (Brown, Halpert & Goodale, 2005; Goodale & Murphy, 1997). Note, that this was even the case when grasping was tested at much larger visual eccentricities than in our experiment (i.e., up to 70º of visual angle, see Goodale & Murphy, 1997). Given the fact that MGA usually increases when movements are performed in visual eccentricity and given the assumption that the Garner target may have shifted into the observer's periphery under dual-task conditions, one would predict larger MGA for dual-task conditions. However, such pattern was not found in our results. A repeated-measures ANOVA revealed no main effect of dual-tasking, $F(2,46) = 0.43$, $p = .653$, $\eta_p^2 = .018$, Garner Interference, $F(1,23)= 0.26$, $p = .618$, $\eta_p^2 = .011$, and no interaction effect, $F(2,45) = 0.35$, $p = .354$, $\eta_p^2 = .044$, on MGA. These findings suggest that it is unlikely that our findings on MGA variability are caused by a changed oculomotor strategy.

Finally, regarding the fact that we used an open-loop vision condition, it seems surprising that we did not find a Garner Interference on RTs given that such an effect was found in a previous study that employed an open-loop vision condition to encourage participants to pre-plan their movements during the RT-interval (Hesse & Schenk, 2013). However, in contrast to this previous experiment, we did not vary the position of the target objects on a trial by trial basis. In our opinion, this difference might be responsible for our failure to replicate Garner Interference effects on RTs during open-loop grasping.

In summary, our findings combined with those of our previous study suggest that neither RTs nor MTs are reliable measures to detect Garner Interference effects during grasping and that instead accuracy measures (such as MGA variability, MGA slope) and timing measures, which are attuned to the time-course of the decision making process in a grasping task, such as adjustment times, provide more reliable measures for identifying Garner Interference in grasping.

4.2 Dual-tasking

Our second question related to dual-tasking and its effect on perception and action. The PAM suggests that the presence of a secondary task may affect perceptual performance but not the performance in visuomotor tasks that are served by the dorsal stream. Here, we found further evidence that contradicts this claim. Similar to previous studies (e.g., Kunde et al., 2007; Singhal et al., 2007) we found that RTs of the grasping response were clearly affected by the presence of a secondary perceptual task. In contrast, we found no clear dual-task effect on MTs. This is in line with other studies investigating grasping movements in the presence of an additional visuo-attentional RSVP task (Liu et al., 2008; Hesse & Deubel, 2011). As argued by Hesse and Deubel (2011) the lack of dual-task interference on MTs may be related to the fact that objects were presented at the very same location throughout the experiment. Hence, participants may quickly learn the required movement path to reach that location and automate that aspect of the movement. Consequently, MTs will be become less susceptible to interference effects. The situation for MGA is different. In contrast to target location, the size of the target object changed from trial to trial meaning that observers were required to program and adjust their grip accordingly in every trial. This prevents automation and may thus increase the sensitivity of grip-related variables to dual-task effects.

Interestingly, looking at the accuracy of the grasping response, we found that dual-tasking effects became primarily apparent when the secondary task involved attending to object shape. In other words, dual-task costs were higher when the secondary task involved similar features as the grasping task (i.e., the processing of object shape). Specifically, in the dual-task shape condition the slopes of the function relating MGA to object size became shallower indicating a less accurate grip adjustment and adjustment times were delayed by about 50 ms in comparison to the baseline and the dual-task colour condition. Only MGA variability did not show any dual-task costs even when there was high similarity between the primary and the secondary task. Again, based on the fact that the size of MGA remained constant in all conditions, we think it is unlikely that the reduced slopes in the dual-task condition and the delayed adjustment times are caused by participants shifting their gaze away from the grasping target toward the RSVP task. This is further supported by the finding that the occurrence and size of dual-task costs seemed to depend on the similarity between the primary and the secondary task. When the secondary task required participants to attend to an object feature that was also relevant for dealing with the primary task (i.e., object shape in our study) as compared to a task-irrelevant object feature (such as object colour), dual-task costs tended to increase and occurred a bit more reliably. In particular, adjustment times were longer and the slopes were shallower in the dual-task shape than in the dual-task colour conditions while there was no difference between the dual-task colour and the single-task conditions. Hence, the failure of previous studies to detect dual-task costs in grasping may, at least partly, be related to their choice of the secondary tasks. Finally, as mentioned above, we cannot fully exclude the possibility that the introduction of a secondary visual task may have altered the gaze behaviour of our observers. However, a recent study by Göhringer, Löhr-Limpens, and Schenk (2018) examined the effects of a secondary task on obstacle-avoidance behaviour and found reliable dual-task effects when fixation was controlled.

There is one further alternative explanation for the finding that the secondary shape task resulted in more reliable dual-task costs than the secondary colour task that needs to be considered: It is possible that shape task was simply more difficult than the colour task. We tried to avoid such differences by piloting both secondary tasks on their own and by adjusting the parameters of the two tasks to achieve a common accuracy level of approximately 85%. Nevertheless, we cannot rule out that small differences in difficulty persisted. This uncertainty does, however, not affect our main conclusion that grasping is subject to dual-tasks costs. Importantly, for our main question of whether or not actions are susceptible for dual-task interferences it is not crucial whether we attribute the observed dual-task costs to the fact that one of the secondary tasks was more similar to the primary task thus tapping into *the same* processing resources, or to the fact that one of the secondary task was more difficult thus requiring *more* processing resources. Either way, the findings show that a secondary visuo-attentional task can cause reliable dual-task costs for a primary action task.

Based on these findings, we would argue that previous claims of dual-tasking immunity of the action system were a result of a) the analysis of a very small subset of performance measures (e.g., Liu et al., 2008) and/or b) the choice of secondary tasks that were either too distinct from the action task (e.g., Singhal et al., 2007), or potentially too easy. In line with the suggestion that movements need to be analysed in more detail in order to unveil dual-task costs during grasping, Hesse and colleagues (2012) have shown in their previous studies that a secondary visuo-attentional task primarily affects the early adjustment of the grip to object size (i.e., they found that the adjustment of the hand to object size was delayed in dual-task conditions). Finally, another discrepancy between studies that showed clear dual-task interference in action tasks and the study by Singhal et al. (2007) that did not find substantial dual-tasking costs lies in the timing of the secondary task. Singhal and colleagues presented a short auditory stimulus (50 ms) to which participants had to respond at the beginning of the trial. In contrast, we employed a RSVP paradigm with stimuli being presented over the whole duration of the grasp. Targets could occur at any moment in time during action planning and execution meaning that primary and secondary task had to be executed truly simultaneously and could not be performed sequentially. To sum up, the findings from our current study and those from previous studies (Hesse & Deubel, 2011; Hesse et al., 2012; Janczyk & Kunde, 2010) suggest that both, action and perception are susceptible to dual-task costs, but also that effects can be missed if experimental methods and measures are not sensitive enough.

4.3 Interaction between Garner Interference and Dual-Tasking

Our third research question, addressed the issue of whether combining the Garner paradigm with a dual-tasking condition might increase the size of the Garner Interference effect, thereby potentially making it easier to detect. In addition, we aimed to test whether the specific demands of the secondary task condition might also modulate the size of the Garner Interference effect. Specifically we speculated that using a secondary perceptual shape-discrimination task, which requires similar processing strategies as dealing with the Garner task might enhance the Garner Interference effect. If this is true, this should have become apparent in significant interaction effects between the factors Garner Interference and dual-tasking condition in the perceptual task and possibly also for the grasping task. In short, we found no clear evidence for this prediction, as no interaction effects were observed on any of our dependent measures. This finding is in accordance with former studies using the PRP paradigm, suggesting additivity of stimulus onset asynchrony (SOA) and Garner Interference effects in perceptual tasks (Kunde et al., 2007; Janczyk et al., 2010). In these studies, the grasping task did not show any Garner Interference effects, but suffered from a secondary task. In our study, the presence of Garner Interference effects as well as dual-task costs, but a lack of interaction between them, was true for both the perception task as well as the visuomotor grasping task. In other words, even when the dual-task affected RTs reliably indicating that the processing of the primary task was slowed, the size of the Garner Interference effect remained rather stable across all conditions.

The only measure in which the Garner Interference effect was moderated by the dual-task demands, at least descriptively, was MGA-variability. Here, the Garner Interferences seemed indeed increased when a secondary shape discrimination task was employed during grasping. However, at this point, our findings also suggest that the interaction effects between Garner Interference and dual-tasking are subtle and fragile, and that high-powered studies are needed to provide more conclusive evidence for our hypothesis that dual-task demands can moderate Garner effects as reflected in certain kinematic parameters of the grasping movement. Based on our current findings we would suggest that the idea might still hold some promise but replications are required to get a final answer to this question.

5 Conclusions

The PAM is supported by a wide-range of evidence. Some of the evidence has been reviewed and scrutinised quite heavily. Other sources of support have received far less research attention. In this study, we focussed on two claims of the model. Both claims were tested in the past and positive evidence on those tests has been used to argue for the continued validity of the model. One claim is that the dorsal stream and behaviours relying on visual information from the dorsal stream are immune to Garner Interference. The second claim states that dorsal-stream behaviour is immune to interference from a secondary perceptual or cognitive task. In our study, we obtained evidence that contradicts both claims. We therefore conclude that neither evidence from Garner Interference nor evidence from dual-tasking provides unequivocal support for the claim that visual information for perception and action are processed in functionally independent anatomical streams.

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Fig. 1 Objects for the Garner task

Baseline: Objects vary only in length, the dimension relevant for the Garner task. *Filter:* Objects vary in length and width, i.e. also in the dimension irrelevant for the Garner task

Fig. 2 Perceptual data

a) Mean reaction times from the perceptual experiment. *Control*: Garner paradigm single-task condition; *Colour:* Garner paradigm with additional colour RSVP task (dual-task colour); *Shape*: Garner paradigm with additional shape RSVP task (dual-task shape). Garner baseline conditions are shown in black, filter conditions in white. **b)** Differences in reaction time between baseline and filter conditions of the Garner paradigm. Error bars depict ± 1 SEM

Fig. 3 Reaction times in grasping

a) Mean reaction times from the grasping experiment. *Control*: Garner paradigm single-task condition; *Colour:* Garner paradigm with additional colour RSVP task (dual-task colour); *Shape*: Garner paradigm with additional shape RSVP task (dual-task shape). Garner baseline conditions are shown in black, filter conditions in white. **b)** Differences in reaction time between baseline and filter conditions of the Garner paradigm. Error bars depict ± 1 SEM

Fig. 4 Adjustment times of hand opening to object size

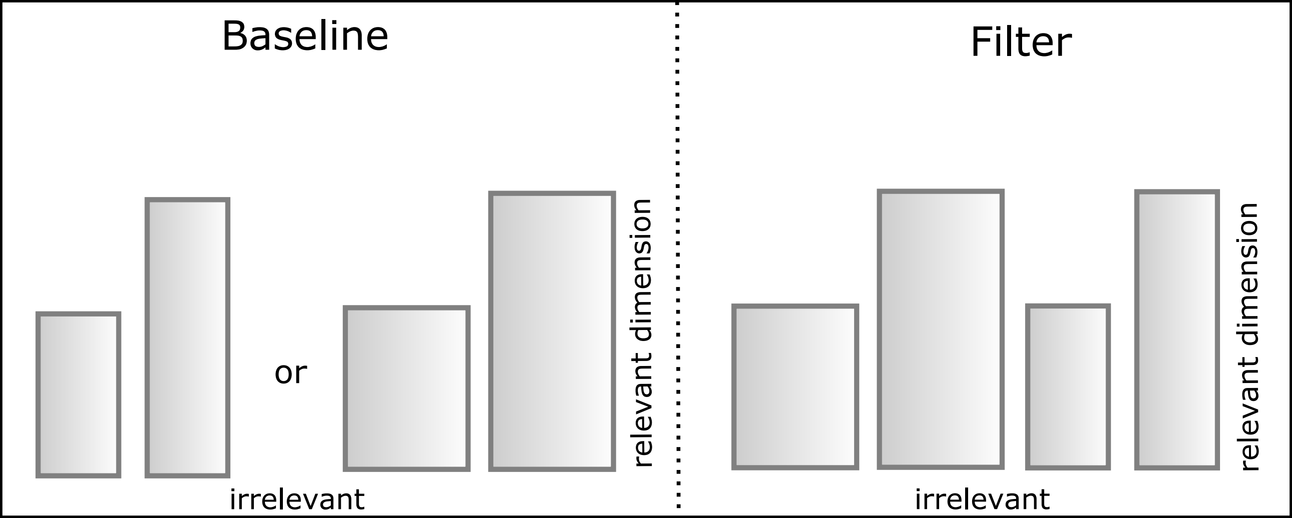
a) Mean adjustment times, i.e. the point in time when the mean hand opening for long objects exceeded that for short objects for at least 10mm (half a difference between the object lengths). *Control*: Garner paradigm single-task condition; *Colour:* Garner paradigm with additional colour RSVP task (dual-task colour); *Shape*: Garner paradigm with additional shape RSVP task (dual-task shape). Garner baseline conditions are shown in black, filter conditions in white. **b)** Differences in the slopes of the adjustment times between baseline and filter conditions of the Garner paradigm. Error bars depict ± 1 SEM

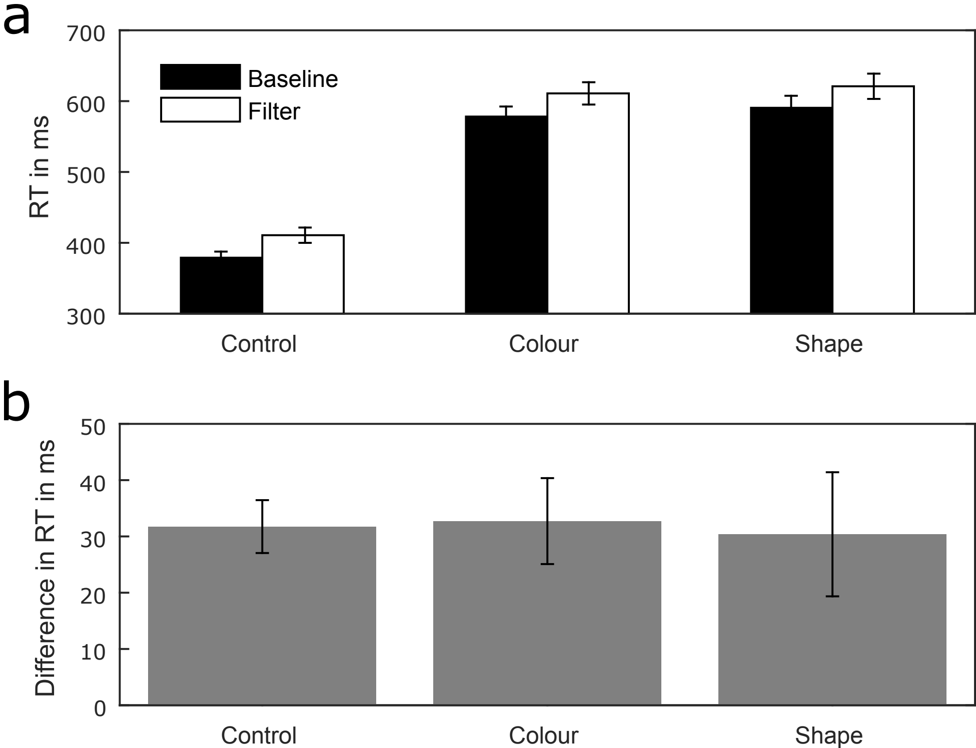
Fig. 5 Variability of peak hand opening

a) Mean standard deviations (STD) of the maximum grip aperture (MGA). *Control*: Garner paradigm single-task condition; *Colour:* Garner paradigm with additional colour RSVP task (dual-task colour); *Shape*: Garner paradigm with additional shape RSVP task (dual-task shape). Garner baseline conditions are shown in black, filter conditions in white. **b)** Differences in mean STD of the MGA between baseline and filter conditions of the Garner paradigm. Error bars depict ± 1 SEM

Fig. 6 Adjustment of hand opening to object size

a) Mean slopes of the linear regression between maximum grip aperture (MGA) and object size. *Control*: Garner paradigm single-task condition; *Colour:* Garner paradigm with additional colour RSVP task (dual-task colour); *Shape*: Garner paradigm with additional shape RSVP task (dual-task shape). Garner baseline conditions are shown in black, filter conditions in white. **b)** Differences in the slopes of the linear regression between MGA and object size between baseline and filter conditions of the Garner paradigm. Error bars depict ± 1 SEM. N.B.: Higher slopes reflect better adjustment, so negative differences indicate Garner Interference effects


Baseline
or
relevant dimension
irrelevant
Filter
relevant dimension
irrelevant


a
700
600
500
400
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RT in ms
Baseline
Filter
Control
Colour
Shape
b
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30
20
10
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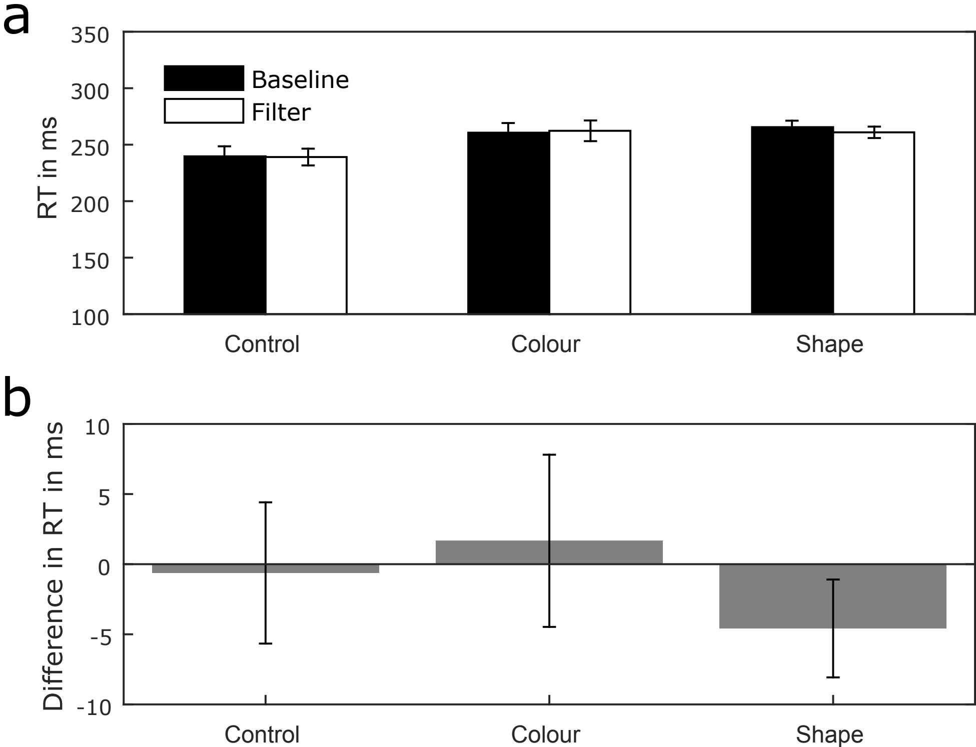
Difference in RT in ms
Control
Colour
Shape


a
350
300
250
200
150
100
RT in ms
Baseline
Filter
Control
Colour
Shape
b
10
5
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-5
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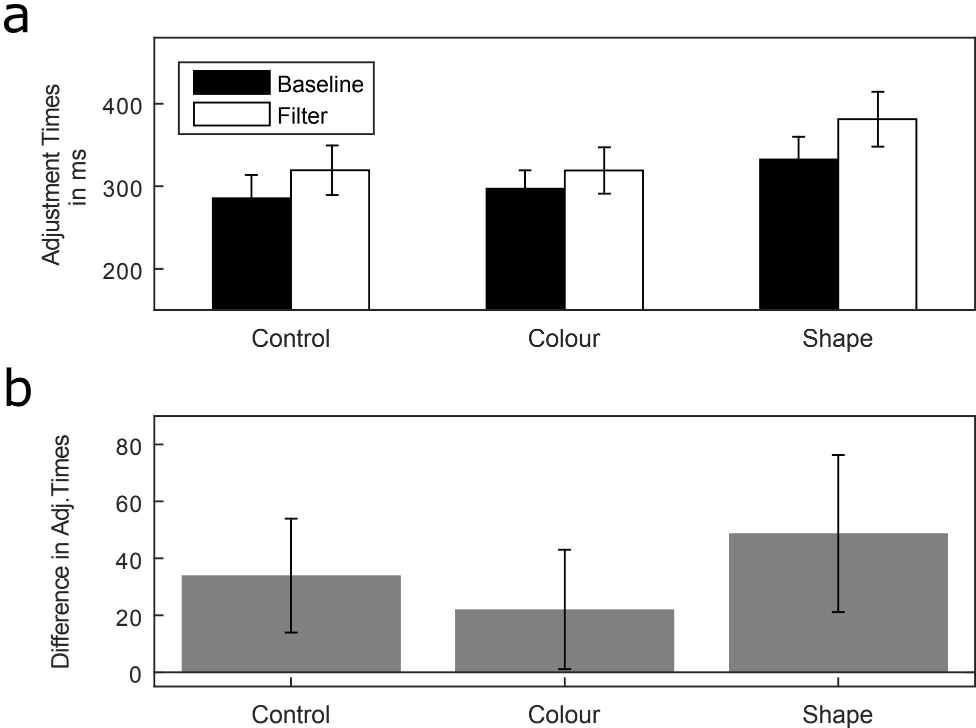
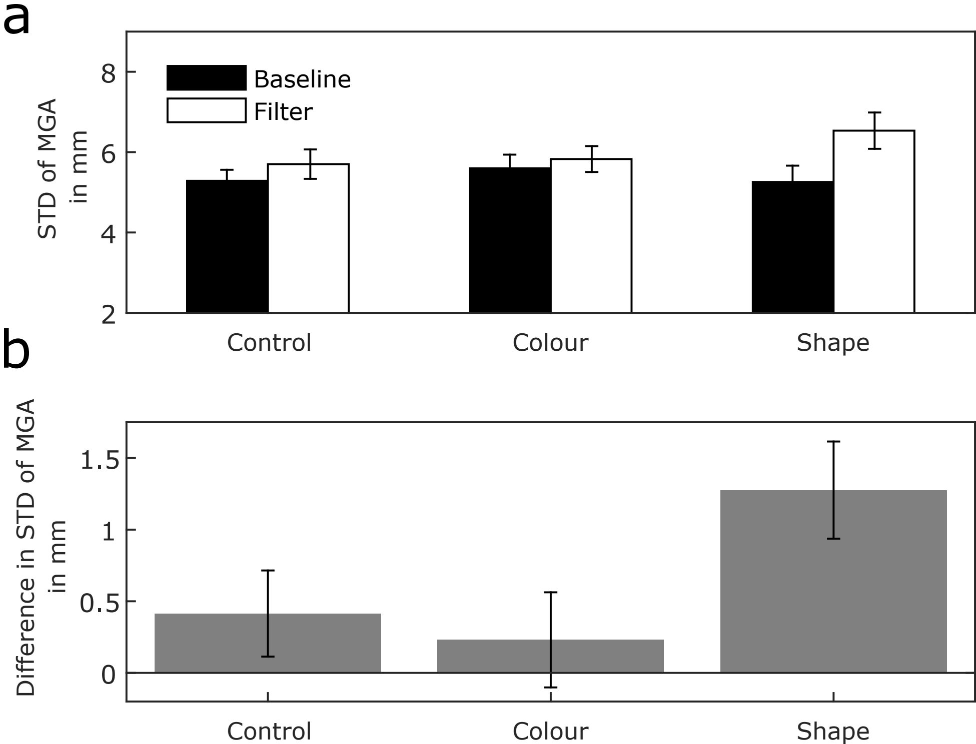
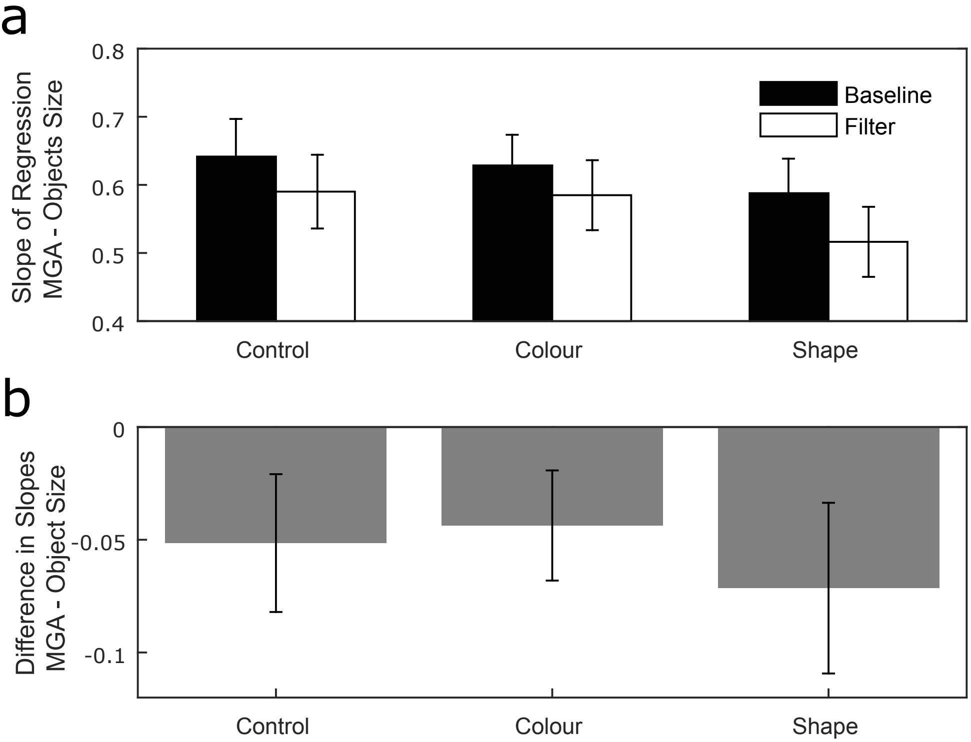
Difference in RT in ms
Control
Colour
Shape


a
Baseline
Filter
Adjustment Times in ms
400
300
200
Control
Colour
Shape
b
Difference in Adj. Times
80
60
40
20
0
Control
Colour
Shape


a
8
6
4
2
STD of MGA in mm
Baseline
Filter
Control
Colour
Shape
b
1.5
1
0.5
0
Difference in STD of MGA in mm
Control
Colour
Shape


a
Slope of Regression
MGA - Objects Size
0.8
0.7
0.6
0.5
0.4
Baseline
Filter
Control
Colour
Shape
b
Difference in Slopes
MGA - Object Size
0
-0.05
-0.1
Control
Colour
Shape