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Reviewing Evidence for the Perception–Action Model From Garner Interference

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It is a widely accepted notion that visual information in the brain is processed via two parallel but separate cortical pathways, the ventral stream for visual perception and the dorsal stream for visuomotor actions. Perception–action dissociations from behavioral experiments are often cited as supportive evidence and one such example is Garner interference: It is assumed that perceptual/ventrally processed tasks suffer Garner interference, while visuomotor/dorsally processed tasks are immune to it (Ganel & Goodale, 2003). Ideally, this dissociation is demonstrated by comparing manual size estimation (assumed ventrally processed) with grasping (assumed dorsally processed). However, few studies actually made this comparison. We addressed this empirical shortage with two improved replications, yielding smaller effects of Garner interference in manual estimation than previous studies reported. In two subsequent experiments, we attempted to modulate Garner interference by manipulating the temporal profile of participants' responses, building on previous work (Hesse & Schenk, 2013) and extending it to manual estimation. We conclude with a literature review covering all relevant studies on Garner interference. Contrary to previous claims, the currently available evidence for a perception–action dissociation from Garner interference is insufficient to support a ventral–dorsal dissociation.

Public Significance Statement

This study investigates whether there are systematic differences between processing of visual information for visually guided actions and perceptual awareness. Previous studies found that actions are processed very differently and are less distracted by task-irrelevant information than perceptual awareness. If true, this would have far-reaching consequences for the understanding of how and where visual information is processed in the human brain and would also have practical consequences for situations where distractions can threaten safety, like driving a car or flying an airplane. Our findings, however, suggest that there is not such a neat split between action and perceptual awareness as currently thought—with all the consequences for theorizing about the brain as well as for the design of safety critical devices.

Keywords: perception, action, grasping, manual estimation, Garner interference

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Do the dorsal and ventral cortical streams process information in different ways? According to the Perception–Action Model (PAM; Goodale & Milner, 1992), there is a sharp and fundamental division of labor between these streams: Visually guided actions are assumed to be processed in the dorsal stream, while visual perception is assumed to be processed in the ventral stream. The ventral stream is assumed to be involved in computation of "object descriptions that permit identification and recognition," functions that are "generally understood as 'visual perception'" (Goodale & Milner, 1992, p. 20). As is customary in this literature, we will henceforth use the term "perception" to refer to these functions.

While even opponents of the PAM concede that it is a useful scientific model (Schenk & Hesse, 2018), it turns out that evidence that has been counted as strong support for the PAM has been called into question. This contradictory evidence comes from effects of visual illusions (Kopiske et al., 2016) and adherence to Weber's law (Bhatia et al., 2022) in perception as well as in action. Here, we focus on one further central experimental approach thought to provide evidence for the PAM: Garner interference (Garner, 1974). In the following, we provide an overview of those studies that used Garner interference in the context of the PAM starting with Ganel and Goodale (2003). In this course, we will highlight that only very few studies (Ganel & Goodale, 2003, 2014) provide the critical comparison between perception and action that would be necessary to support the PAM. This surprising lack of empirical data will be the starting point of our own investigation involving four experiments. The total available evidence is assessed as the final part of this article.

Behavioral Perception–Action Dissociations

The PAM was first proposed based on perception–action double dissociations in brain lesion patients with visual form agnosia (most notably patient DF) and optic ataxia (Goodale et al., 1991). However, these findings have been subject to debate and controversy (Schenk, 2006; for reviews see Schenk et al., 2011; Schenk & McIntosh, 2010; Westwood & Goodale, 2011). For this reason, behavioral experiments and neuroimaging studies have been put forward as additional evidence in favor of the PAM, and we here focus on such behavioral evidence from healthy adults.

Broadly speaking, three lines of behavioral results (perception–action dissociations) are thought to support the idea of the PAM: (a) actions may be immune to visual illusions (Aglioti et al., 1995), (b) actions may not adhere to Weber's law (Ganel et al., 2008), and (c) actions may not suffer Garner interference (Ganel & Goodale, 2003). Whether there is a perception–action dissociation regarding visual illusions was a hotly debated topic (Franz & Gegenfurtner, 2008), which was tackled by a large, multilab registered report (Kopiske et al., 2016), with the conclusion that both perception and action are sensitive to effects of visual illusions (see also Kopiske et al., 2017; Whitwell & Goodale, 2017). Recently, it was also suggested that actions like grasping do indeed follow Weber's law, as do perceptual tasks (Bhatia et al., 2022). Thus, the first two lines of evidence cannot be considered as unambiguously supporting the PAM.

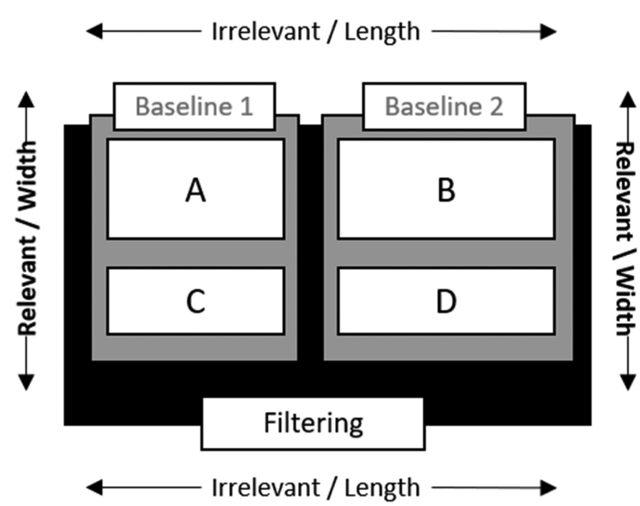
Therefore, the third line of evidence, that is, Garner interference, becomes particularly important to investigate. Several studies investigated the prediction of the PAM that Garner interference is absent in actions but present in perceptual tasks (Eloka et al., 2015; Ganel & Goodale, 2003, 2014; Hesse & Schenk, 2013; Janczyk et al., 2010; Janczyk & Kunde, 2010, 2016; Kunde et al., 2007; Löhr-Limpens et al., 2020; Schum et al., 2012). However, as will be detailed below, most of these studies compared tasks with dissimilar task demands and, hence, cannot be taken as strong tests for the PAM.

Garner Interference

Garner interference is assessed with a classic experimental design developed to test whether certain stimulus properties, or dimensions, can be processed independently of each other (Garner, 1974). Consider the prototypical example of a rectangle with dimensions length and width. A stimulus set of four rectangles is created by a factorial combination of two lengths and two widths (Figure 1; cf. Felfoldy, 1974). Width is the task-relevant dimension, meaning that the objects should be classified along their width as either "narrow" or "wide." It is then tested whether participants can ignore changes in the task-irrelevant dimension length by comparing the reaction times (RTs) between two conditions in a speeded-classification task (Figure 1): In the baseline condition, the stimulus set consists of only objects of the same length but with differing widths, and therefore, there is only variation along the task-relevant dimension. By contrast, in the filtering condition, the stimulus set consists of all four objects, which have differing width and length, thereby creating variation of task-relevant and task-irrelevant dimensions. For some dimensions, like length and width of a rectangle, the typical result is that participants are faster in the baseline condition as compared to the filtering condition (Garner, 1974). This RT difference is called Garner interference, and the dimensions are termed integral dimensions. An example of nonintegral or separable

Figure 1

Illustration of Baseline and Filtering Conditions in a Garner Experiment



Note. Stimuli in baseline and filtering conditions of a typical Garner experiment with four rectangular objects. The relevant dimension is width; therefore, participants must classify the objects as "wide" or "narrow." The baseline condition consists of objects differing only along the relevant dimension width. There are two baseline blocks: Baseline 1 which consists of only short objects (A and C) and Baseline 2 with only long objects (B and D). The filtering condition consists of two identical blocks with all four objects (A, B, C, and D) in each block.

dimensions that do not result in Garner interference is the angle and size of the diameter of a circle (Garner & Felfoldy, 1970).

Studies in the context of the PAM used object dimensions that were known to be integral (length and width of rectangles; Felfoldy, 1974) and interpreted the presence of Garner interference as indicating that variation in the task-irrelevant dimension could not be ignored and interfered with processing of the task-relevant dimension. In the following, we describe how the presence or absence of Garner interference is then typically used to demonstrate a perception–action dissociation.

Garner Interference and the Two Visual Streams

To demonstrate perception–action dissociations, two tasks are typically compared: an action task (assumed to be dorsally processed) and a perceptual task (assumed to be ventrally processed). Ideally, the action task is precision grasping (using index finger and thumb), and the perceptual task is manual (size) estimation. In manual estimation, participants estimate and indicate the size of a target object with their index finger and thumb. Manual estimation is assumed to tap into ventral, perceptual processes and provide a "manual read-out of what participants perceive" (Haffenden & Goodale, 1998, p. 125) while keeping many aspects of precision grasping. Thus, it is an ideal comparison to grasping. This is important because the PAM assumes different underlying processing in grasping and manual estimation, while both are considered to involve similar task demands (Ganel & Goodale, 2003). In our arguments, we will accept this assumption to be true, although one may question whether manual estimation is really a perceptual task (Franz, 2003) or if the task demands are comparable to grasping (e.g., see the General Discussion section and Figure 10).

Ganel and Goodale (2003) were the first to use Garner interference in the context of the PAM. They reasoned that perception requires a representation that encodes both relevant and irrelevant features in a holistic way, thereby preventing access to a single dimension and yielding Garner interference. Actions, on the other hand, would need an absolute and analytical representation of only the relevant features, thereby allowing access to the relevant dimension and being able to ignore the task-irrelevant dimension. Consequently, actions should not show Garner interference.

Ganel and Goodale (2003) used four cuboidal objects made of a factorial combination of two different lengths and widths (same as those used by Felfoldy, 1974). These stimuli were used in two tasks in their Experiment 1: In perceptual speeded classification (used originally by Garner, 1974), participants pressed buttons to judge a stimulus as "narrow" or "wide." In grasping, participants grasped a stimulus along its width. In speeded classification, RTs were shorter in baseline than in filtering conditions, thus showing Garner interference. In grasping, however, RTs (and other dependent variables) were similar in both conditions, such that Garner interference was small and not significantly different from zero. Ganel and Goodale (2003) inferred that object shape is holistically processed in speeded classification, while it is analytically processed in grasping. They concluded that this result "helps to explain why separate cortical pathways have evolved for these two different kinds of visual processing: a ventral stream for perception and a dorsal stream for action" (Ganel & Goodale, 2003, p. 667).

Importantly, however, Ganel and Goodale (2003) conceded that the two tasks used in their Experiment 1 had very different task demands, and the results might simply be explained by this dissimilarity and not by a dissociation at the neural level. To address this, participants in their Experiment 2 estimated the width of the rectangular objects with their finger and thumb, thus performing a manual estimation task. The PAM assumes that task demands in grasping and manual estimation are sufficiently similar such that performance differences can be interpreted as differences in dorsal versus ventral processing (Goodale et al., 1994; Haffenden & Goodale, 1998). Strikingly, manual estimation showed large Garner interference in RTs (and other dependent variables). These effects were even larger than in speeded classification (see Figure 6). This strong dissociation was therefore interpreted as indicating holistic processing in manual estimation and speeded classification (both ventral stream) but analytical processing in grasping (dorsal stream).

To summarize, the crucial comparison is between grasping and manual estimation. In the framework of the PAM, only these tasks are sufficiently similar to draw strong inferences from the comparison. Given this, it is surprising that only two studies actually investigated manual estimation and reported Garner interference (Ganel & Goodale, 2003, 2014). In one other study, participants performed manual estimation, but Garner interference was not significant and the results were only reported in a footnote (Schum et al., 2012, footnote 2). Thus, there seems to be a shortage of empirical support for Garner interference in the crucial manual estimation task. The experiments reported in the present study aim to fill this gap.

Overview of This Study

Our primary goal was to add empirical data on Garner interference in manual estimation. Experiment 1 is a preregistered replication of Ganel and Goodale (2003) with a repeated-measures design and two grasping tasks (open loop and closed loop), manual estimation, and perceptual speeded classification. No previous study employed such a comprehensive repeated-measures design with all these tasks.

The Garner interference effect in manual estimation in our Experiment 1 was very small in contrast to previous studies (Ganel & Goodale, 2003, 2014). We therefore focused on manual estimation in Experiments 2–4. However, in none of these experiments did we replicate the expected and previously reported 20–30 ms Garner interference in manual estimation.

To better understand the nature of these tasks, we quantitatively compared the size of the Garner interference effect across the tasks, that is, how much Garner interference is observed in grasping or speeded classification or manual estimation (rather than only focusing on whether it is significantly different from zero or not, as was the focus in Ganel & Goodale, 2003, and many other studies). Thus, we adopted an "estimation mind set" (Stanley & Spence, 2014) and performed a comprehensive and quantitative literature review of studies on Garner interference to summarize and compare the currently available data on this topic.

Experiment 1: All Tasks in Repeated-Measures Design

This experiment attempted to replicate the results of Ganel and Goodale (2003). While that study employed a between-participants design, we used a repeated-measures design and included four tasks: perceptual speeded classification, closed-loop grasping (i.e., visual input available during the grasping movement), open-loop grasping (i.e., without visual input), and manual estimation (closed loop). We also increased the sample size to $n = 24$ (compared to $n \leq 12$ in Ganel & Goodale, 2003) to achieve more power. Both the full repeated-measures design and the increased sample size are improvements and extensions of the original study. We expected to replicate the results of Ganel and Goodale (2003): large Garner interference in speeded classification and manual estimation (perceptual tasks) and small, nonsignificant Garner interference in closed- and open-loop grasping.

Method

The study design, stimuli, and analyses of Ganel and Goodale (2003) were closely followed. Some details which were not provided in the original publication were taken from Ganel and Goodale (2014).

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study, following Journal Article Reporting Standards (Kazak, 2018). This experiment was preregistered on AsPredicted (https://aspredicted.org/YLL_WOC). Data and analysis scripts of all experiments are available at the additional online materials (https://osf.io/tvqp7/). Data collection took place in 2021. Data of all experiments were analyzed and figures were created using R, Version 4.1.1. (R Core Team, 2021) and the packages "pwr" (Champely, 2020), "plotrix" (Lemon, 2006), and "ez" (Lawrence, 2016). The upper panels of Figures 2 and 3 contain data digitized from Ganel and Goodale (2003, Figures 2 and 3) and were recreated in R.

Participants and Power Analysis

In total, 24 right-handed participants (17 women, seven men, age range = 18–44 years, $M_{\text{age}} = 26.6$) took part in the experiment. Most participants were students or employees at the University of Tübingen, from diverse nationalities, and spoke German and/or English. Participation was voluntary and participants gave written, informed consent prior to data collection. They were compensated with 10€/hour or course credit for participation. The study was approved by the ethics committee of the University of Tübingen and was conducted in accordance with the principles of the Declaration of Helsinki.

We planned to collect 24 valid participants (after exclusions, but note that our exclusion criteria did not lead to the exclusion of any participants, see below). Our effect of interest is Garner interference in all tasks. Detailed power analyses are described in the Appendix. Based on effect sizes from Ganel and Goodale (2003), we had a power of $1 - \beta = .96$ for detecting Garner interference in speeded classification and $1 - \beta = .99$ in manual estimation (see Table A1 in the Appendix) with one-tailed paired t tests. The most important comparison for the PAM is the prediction of Garner interference in manual estimation being greater than in grasping. We therefore tested for a difference between those effects (i.e., larger Garner interference in manual estimation than in grasping). The power for this comparison was at least $1 - \beta = .92$ for a one-tailed paired t test (see Table A2 in the Appendix).

Stimuli

The stimuli were identical to those used by Ganel and Goodale (2003), that is, rectangular blocks made of black, rigid plastic in a factorial combination of two different widths (30 and 35.7 mm) and lengths (63 and 75 mm). Each block was 15-mm thick.

Apparatus

Participants sat in a height-adjustable chair in front of a table on which an liquid crystal display monitor was placed with the screen facing up. The liquid crystal display monitor (screen diagonal: 54.6 cm; Samsung Syncmaster2233, Samsung group, Seoul, South Korea) was connected to a computer and used to display instructions, start location, and stimulus positions. Participants performed the experiment on the surface of this monitor. Participants wore liquid-crystal shutter goggles (PLATO goggles, Translucent Technologies Inc., Toronto, Ontario, Canada; see Milgram, 1987) to control stimulus presentation time. RTs and grip apertures were calculated from data recorded by an Optotrak Certus (Northern Digital, Waterloo, Ontario, Canada) using small infrared light emitting diodes (or markers) attached to the nails of the index finger and thumb of the participant's right hand using adhesive putty (UHU-Patafix, UHU GmbH, Bühl, Germany). Coordinates in three-dimensional (3D) space were recorded at a sampling frequency of 200 Hz. Participants' responses in the speeded classification and manual estimation tasks were registered through custom-built buttons, digitized with a DT9812 box (EconSeries Data-Translation/Acquisition circuit, Measurement Computing Corporation, Georgetown, Massachusetts, United States). MATLAB (MathWorks, Natick, Massachusetts, United States) was used for stimulus presentation with the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007) and the Optotrak Toolbox by V. H. Franz (https://www.ecogsci.cs.uni-tuebingen.de/OptotrakToolbox).

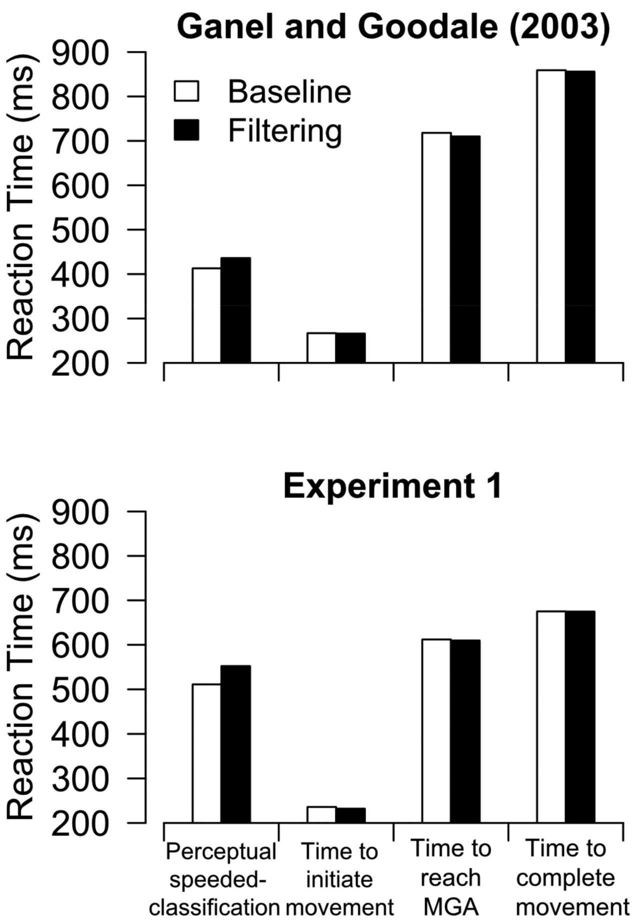
Procedure

All participants performed four tasks: perceptual speeded classification, manual estimation, open-loop grasping, and closed-loop grasping. The stimuli were presented in two conditions, baseline and filtering (Figure 1). At the beginning of each task, participants performed eight to 10 practice trials, until they felt comfortable with the task. Participants performed two blocks of each condition and every block consisted of 32 trials, for a total of 128 trials (per task) in four blocks. The condition order was counterbalanced such that participants performed four blocks of BBFF or FFBB (B = baseline, F = filtering) for each task. The order of tasks was partially counterbalanced. Participants were instructed to be as accurate and fast as possible in all the tasks. In all tasks, the experimenter placed the stimulus at a specified location, and then the trial began with the goggles turning transparent.

In the perceptual speeded-classification task, participants judged the stimulus as narrow or wide. For all participants, the left button mapped to a "narrow" response, which they pressed using their right-hand index finger, and the right button, pressed using their right-hand middle finger, mapped to a "wide" response (following the procedure of Ganel & Goodale, 2003). The goggles turned opaque after 1,000 ms or if a button press was registered, whichever occurred earlier.

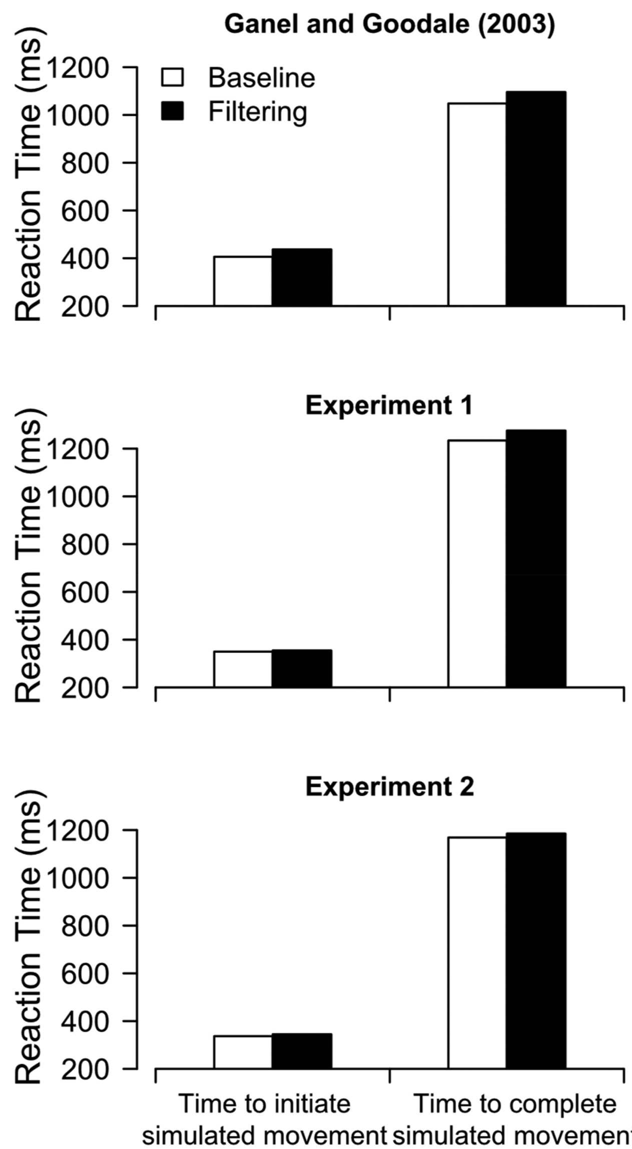
In the manual estimation task, participants estimated the width of the stimulus with the distance between their index finger and thumb. At the start of a trial, participants kept their index finger and thumb pinched together at the start position. When the goggles turned

Figure 2
Comparison of Ganel and Goodale's (2003) Experiment 1 and our Experiment 1



Note. The results of speeded classification and closed-loop grasping. Axis labels are identical to Ganel and Goodale (2003) and represent different time-related dependent variables: Perceptual speeded classification = RT in speeded classification; time to initiate movement = RT in grasping; time to reach MGA = MGA time in grasping; time to complete movement = touched time in grasping. RT = reaction time; MGA = maximum grip aperture. Upper panel adapted from "Visual Control of Action but not Perception Requires Analytical Processing of Object Shape," by T. Ganel and M. A. Goodale, 2003, *Nature, 426*(6967), p. 666 (https://doi.org/10.1038/nature02156). Copyright 2003 by Springer Nature. Adapted with permission.

Figure 3
Comparison of Manual Estimation: Ganel and Goodale (2003) and Our Experiments 1 and 2



Note. The results of manual estimation ("simulated grasping"; Ganel & Goodale, 2003). Axis labels are identical to Ganel and Goodale (2003) and represent different time-related dependent variables: Time to initiate simulated movement = RT in manual estimation; time to complete simulated movement = ManEstTime. RT = reaction time; ManEstTime = time to complete manual estimation. Upper panel adapted from "Visual Control of Action but not Perception Requires Analytical Processing of Object Shape," by T. Ganel and M. A. Goodale, 2003, *Nature, 426*(6967), p. 666 (https://doi.org/10.1038/nature02156). Copyright 2003 by Springer Nature. Adapted with permission.

transparent, participants moved their fingers to a specified location on the monitor surface, made a width estimate with index finger and thumb, and pressed a button with their left hand indicating the completion of the estimation. Then, they grasped the object with their right-hand index finger and thumb, placed it at a specified location to their right, and returned their hand to the start position. The postestimation grasp was performed so that participants receive equivalent haptic feedback in manual estimation as in grasping from touching the target object. This is standard practice in manual estimation tasks and followed previous studies on Garner interference (Ganel & Goodale, 2003, 2014; Schum et al., 2012), although it is unclear if the delayed haptic information in manual estimation is comparable to the immediate feedback available in grasping. The goggles turned opaque after 2,000 ms (closed-loop manual estimation). The distance between the start position and manual estimate (ManEst) position was 15 cm, and the distance between the start position and the stimulus was 32 cm. Trials where participants had problems with the postestimation grasp (collided with the object or dropped it after grasping) or could not complete the task before goggles turned opaque were deleted and repeated at a random time later in the block. The experimenter also deleted trials (repeated randomly later) where the participant's aperture velocity at the time of button press was too high, meaning that the participant did not synchronize indication of the estimate with the button press. Trials with missing position information (Optotrak markers obstructed from view of Optotrak) at the time of indicating the width estimate were also deleted and repeated.

In closed-loop grasping, participants grasped the stimulus along its width with their index finger and thumb (i.e., with a precision grip) and placed it at a nearby location. A trial began with participants' index finger and thumb pinched together at the start position, and when the goggles turned transparent, they reached toward the object to grasp it. The goggles turned opaque after 2,000 ms. The participants had full vision of their hand and the stimulus throughout. Distance between the object and start position was approximately 32 cm. Trials where participants had problems with the grasp (collided with the object or dropped it after grasping), or could not complete the task before goggles turned opaque, or trials with missing position information were deleted and repeated at a random time later.

Open-loop grasping was identical to closed-loop grasping in all respects, with the exception that the goggles turned opaque as soon as the participants' hand began to move, that is, at movement onset. Therefore, no online visual feedback about the relation between hand and object was available to the participants.

Dependent Variables

RTs in the perceptual speeded-classification task were calculated as the time between the goggles turning transparent and the button press. We also calculated the accuracy of the responses.

RTs in the grasping tasks were measured by the Optotrak as the time point when the participants' fingers left the start position (movement onset). This was determined by a velocity criterion: The first time point when either the finger or thumb marker's velocity exceeded 0.025 m/s. The touched time or total time in grasping was calculated as the first time point when either finger or thumb marker was closer than 60 mm to the midpoint of the object and less than 5 mm above the object (in the Z direction; see Franz et al., 2005) relative to movement onset. The maximum grip aperture (MGA) was calculated as the maximum distance between the finger and thumb occurring during the movement. The MGATime was the time point at which the MGA occurred.

RTs in the manual estimation task were determined in the same way as for grasping. The time to complete manual estimation, ManEstTime, was the time from the goggles becoming transparent to the button press indicating the completion of the estimate. Movement time (MT) was calculated as the time between movement start (RT) and completion (ManEstTime), and therefore, MT = ManEstTime − RT. Since the ManEstTime includes the RT, the ManEstTime will be correlated with the RT. The MT should thus be a more independent measure (from RT) than ManEstTime. Finally, the ManEst of the width of the stimuli was determined as the finger aperture at the time point of the button press.

We also performed all analyses when applying slightly different methods to determine movement onset and offset as used by Ganel and Goodale (2014) to calculate the dependent variables in grasping and manual estimation. These analyses led to essentially similar results, which we report in Table S1 in the online supplemental materials.

Preregistered Analyses

Trials with RTs shorter than 100 ms or longer than 1,500 ms were first excluded. Trials with RT beyond the $M \pm 2\ SD$ for each participant and condition were also excluded. For speeded classification, any participant with more than 10% errors would have been excluded, but all participants achieved accuracies above 90%. All these exclusion criteria were preregistered and led to the exclusion of 7% trials in speeded classification, 6% trials in closed-loop grasping, 5% trials in open-loop grasping, and 5% trials in manual estimation (we also analyzed the data including these trials with essentially the same results, aside from small numerical differences).

For grasping, there was a further exclusion criterion that was not preregistered: trials where the MGA was achieved at the time of touching the object were excluded. This is necessary because touching the object biases the MGA to the true object size. This led to the exclusion of further 1% trials each in closed- and open-loop grasping.

A repeated-measures analysis of variance (ANOVA) on RTs with factors task (speeded classification, manual estimation, grasping open loop, and grasping closed loop) and condition (baseline and filtering) was performed to investigate differences in the Garner interference effect across tasks. For better comparison with the literature, we also used one-tailed paired-samples t tests to test for a difference between baseline and filtering (i.e., the presence of Garner interference) in single tasks.

Analyses That Were Not Preregistered

In addition to the preregistered analyses, we also performed some analyses in response to reviewers' suggestions and as sanity checks to compare our results with those of previous studies, and we describe them below.

Ganel and Goodale (2003) reported Garner interference in ManEstTime in addition to RT. Hence, we also checked for Garner Interference in MT and ManEstTime with one-tailed paired t tests. We also analyzed "variability-based Garner interference," as suggested by Ganel and Goodale (2014). They argued that even when RTs and MTs do not show Garner interference, it might still be reflected in reduced accuracy in filtering than in baseline conditions (the idea being that participants might be able to have the same speed in filtering as in baseline, but at the cost of reduced accuracy). Therefore, they proposed to investigate the within-participant standard deviation of the dependent variables (MGA/ManEst). Because this had not been considered in their 2003 study, Ganel and Goodale (2014) reanalyzed those older data together with their new data and showed for both studies variability-based Garner interference for manual estimation but not for grasping—consistent with the PAM. We performed the same analysis: For each participant, we calculated the within-participants standard deviation of MGA/ManEst ($SD_{\mathrm{MGA}}/SD_{\mathrm{ManEst}}$) in each condition and object size, averaged[1] across object sizes, and performed an

[1] Ganel and Goodale described this procedure in their 2014 study. For better comparison, we follow this procedure, although one might argue that it is statistically more sensible to pool the standard deviations, rather than averaging them.

ANOVA with factors task (manual estimation, grasping open loop, and grasping closed loop) and condition (baseline and filtering). One-tailed paired *t* tests were also performed for results comparable to the literature.

Ganel and Goodale (2003) performed another analysis to check for holistic versus analytical processing: they reasoned that, if the irrelevant dimension (length) has an influence on the response (MGA in grasping and ManEst in manual estimation), the response should be larger for shorter objects than for longer objects because shorter objects will appear wider than longer objects do. This has been named the height–width illusion (Beck et al., 2013; Mazuz et al., 2023; Zitron-Emanuel & Ganel, 2020), which was first reported by Müller-Lyer (1889). This illusion was observed by Ganel and Goodale (2003) in manual estimation, but not in grasping, and was interpreted as further evidence for analytical processing in grasping but holistic processing in manual estimation. We thus calculated the illusion effect by subtracting the responses to the long object (appears narrow due to illusion) from the short object (appears wide) and submitted them to an ANOVA with factors task (grasping open loop, grasping closed loop, and manual estimation) and condition (baseline and filtering). We added the factor condition because Ganel and Goodale (2003) reported the illusion effect for the filtering condition only and we wanted to check if this effect is influenced by condition (see Figure 9). Our effect of interest is a main effect of task, which would indicate that illusion effects are different across tasks.

Reviewers suggested that we also compute Bayes factors to quantify evidence for the competing hypotheses. We reported one-tailed Bayes factors with default priors (prior for the null is a point mass on zero, and prior for the alternative is a truncated Cauchy distribution with width = 0.707, cf. Rouder et al., 2009) for *t* tests in all experiments along with the frequentist results (with results being by-and-large consistent). For this, we used the standard settings of the function “ttestBF” from the R package “BayesFactor” (Morey & Rouder, 2024). In addition, we report Bayes factors using theory-driven priors (Dienes, 2008, 2023), which enabled us to compare the size of Garner interference in manual estimation with grasping and speeded classification. We will henceforth refer to this analysis as the “Bayesian comparison.” To perform this comparison, we focused on RTs because this is the only variable that can be determined in all tasks and is typically reported in studies (Figures 6–9). The comparison can be achieved by using the results of Experiment 1 from speeded classification and grasping as priors: The prior for the null hypothesis was a normal distribution with mean and standard error of the mean (*SEM*) of Garner interference in speeded classification, and the prior for the alternative hypothesis was a normal distribution with mean and *SEM* of Garner interference in grasping (see Table 1). Therefore, the Bayes factor will tell us whether Garner interference in manual estimation is more likely under the null hypothesis (H_0: Garner interference in manual estimation is the same as in speeded classification) than under the alternative hypothesis (H_1: Garner interference in manual estimation is the same as in grasping). This is a critical comparison because it directly tests the results of manual estimation against the assumptions of the PAM, which posits that larger Garner interference occurs in tasks assumed to be processed in the ventral stream like speeded classification, while smaller Garner interference occurs in tasks assumed to be processed in the dorsal stream like grasping (see Dienes, 2008, for a general introduction to this approach of directly testing the theoretical approaches in question). If the Bayesian comparison results in a Bayes factor $BF_{10} > 1$, then there is evidence for the alternative hypothesis, that is, that Garner interference in manual estimation is more similar to grasping, which is assumed to be dorsally processed. If the $BF_{10} < 1$, then there is evidence for the null hypothesis that Garner interference in manual estimation is more similar to speeded classification, which is assumed to be ventrally processed. We interpreted the strength of evidence given by the Bayes factors following Jeffreys (1961): We speak of strong evidence for H_0 for Bayes factors smaller than 1/10, substantial evidence for H_0 for Bayes factors between 1/10 and one-third, inconclusive results for Bayes factors between one-third and 3, substantial evidence for H_1 for Bayes factors between 3 and 10, and strong evidence for H_1 for Bayes factors above 10. Experiments 2, 3, and 4 only involved manual estimation; therefore, we used the grasping and speeded-classification results of Experiment 1 for the Bayesian comparison to the manual estimation results. The analysis code used for the Bayesian comparison is based on Dienes (2008) and can be found as the additional online materials (https://osf.io/tvqp7/).

All values are reported as mean ± *SEM*, unless otherwise specified. Standardized effect sizes are reported as Cohen's d_z (for repeated measures) or generalized eta squared (η^2_G). The Greenhouse–Geisser method (Greenhouse & Geisser, 1959) was used to correct *p* values for ANOVAs with more than two factor levels, and the corresponding ε values are reported. For all tests, a significance level of $\alpha = .05$ was used.

Results

RTs

Accuracies in the speeded-classification task were 98.2 ± 0.3% (baseline condition) and 97.1 ± 0.5% (filtering condition). The slightly higher accuracy in the baseline condition is not simply a speed–accuracy trade-off because participants are also faster in this condition (see below).

RTs as well as the differences in RTs between filtering and baseline conditions (i.e., the Garner interference effects) are listed in Table 1. Later, when we perform our literature review, those values will also be depicted in Figure 6 (for comparison to other studies). We also plotted our results side by side to the results of Ganel and Goodale (2003): Figure 2 shows this comparison for speeded classification and closed-loop grasping; Figure 3 shows manual estimation. On inspection, most results seem comparable, with one notable exception: Manual estimation seems to show smaller Garner interference in our study than in Ganel and Goodale (2003).

The ANOVA on RTs revealed a significant main effect of task, meaning that the tasks had significantly different RTs (see the General Discussion section and Figure 10), $F(3, 69) = 162.31$, $\varepsilon = .65$, $p < .001$, $\eta^2_G = .77$. There was a nonsignificant overall Garner interference effect (main effect of condition), $F(1, 23) = 3.59$, $p = .071$, $\eta^2_G < .01$. Instead, the Garner interference effect was modulated by task, with a Significant Task × Condition Interaction, $F(3, 69) = 5.59$, $\varepsilon = .72$, $p = .005$, $\eta^2_G = .02$.

Next, we tested which task showed a Garner interference effect in RTs. The results are summarized in Table 1: Garner interference was significant in speeded classification but neither in grasping nor in manual estimation. These results partly resemble those of Ganel

Table 1
Reaction Times (in Milliseconds) for Experiment 1

Task	Baseline	Filtering	Difference	$t(23)$	p	d_z	BF_{10}
Speeded classification	511 ± 19	552 ± 19	41 ± 11	3.62	<.001	0.74	64.2
Closed-loop grasping	236 ± 7	232 ± 6	−4 ± 4	−0.94	.822	−0.19	0.12
Open-loop grasping	246 ± 10	246 ± 12	0 ± 7	−0.06	.525	−0.01	0.21
Manual estimation	350 ± 16	355 ± 14	5 ± 13	0.39	.352	0.08	0.29

Note. The reaction times in milliseconds for baseline and filtering conditions, as well as the Garner interference effect (difference = filtering − baseline) for each task of Experiment 1. Values are reported as mean ± standard error of the mean. BF = Bayes factor.

and Goodale (2003), but while these authors reported a significant Garner interference in manual estimation, we did not observe it.

Further, we tested whether Garner interference was larger in manual estimation than in grasping. Again, we found nonsignificant effects: both in manual estimation versus closed-loop grasping (difference = 9 ± 12 ms), $t(23) = 0.73$, $p = .235$, $d_z = 0.15$, $BF_{10} = 0.42$, and in manual estimation versus open-loop grasping (difference = 5 ± 12 ms), $t(23) = 0.45$, $p = .328$, $d_z = 0.09$, $BF_{10} = 0.30$.

The Bayesian comparison of whether Garner interference in manual estimation is more similar to Garner interference in speeded classification (H_0) than in closed-loop grasping (H_1), resulted in a Bayes factor of $BF_{10} = 10.0$, which is substantial evidence that Garner interference in manual estimation is more similar to grasping (H_1) than to speeded classification (H_0).

For MT, the observed Garner interference in manual estimation was numerically large but not significant (37 ± 22 ms), $t(23) = 1.68$, $p = .053$, $d_z = 0.34$, $BF_{10} = 1.37$. A similar result was obtained for ManEstTime (42 ± 25 ms; see Figure 3), $t(23) = 1.70$, $p = .051$, $d_z = 0.35$, $BF_{10} = 1.37$.

Variability

We also analyzed Garner interference in the response variability in grasping (MGA) and manual estimation (ManEst) from our data. The ANOVA revealed main effects of task, $F(2, 46) = 10.47$, $\varepsilon = .97$, $p < .001$, $\eta^2_G = .08$, and condition, $F(1, 23) = 5.50$, $p = .028$, $\eta^2_G = .01$, but the interaction was not significant, $F(2, 46) = 0.03$, $\varepsilon = .89$, $p = .960$, $\eta^2_G < .001$. This suggests that the Garner interference in the variability of the response was not significantly different between tasks (see Table 2 and Figure 8).

Height–Width Illusion

Regarding the height–width illusion effect, the ANOVA resulted in only nonsignificant main effects of task, $F(2, 46) = 2.53$, $\varepsilon = .85$, $p = .100$, $\eta^2_G = .04$, and condition, $F(1, 23) = 0.09$, $p = .769$, $\eta^2_G < .001$, and a nonsignificant interaction, $F(2, 46) = 2.92$, $\varepsilon = .93$, $p = .069$, $\eta^2_G = .03$. Therefore, the illusion effect was not significantly different for grasping and manual estimation (see also Figure 9 for a meta-analysis).

Discussion

Experiment 1 was an attempt to replicate the results of Ganel and Goodale (2003) in a repeated-measures design with perceptual speeded classification, open-loop grasping, closed-loop grasping, and manual estimation tasks. For RTs, we were able to corroborate the results in speeded classification and in grasping. However, we were not able to replicate the important Garner interference in manual estimation. Further, it seems that the difference between grasping and manual estimation is at least smaller than previously assumed, largely due to the very small effect in manual estimation (note that Ganel & Goodale, 2003, did not report a direct comparison between Garner interference in grasping and manual estimation).

The picture is similar for the other movement parameters (time to complete movement, etc.): We can corroborate the results for grasping, but there is no clear Garner interference in manual estimation.

We also found relatively small values for variability-based Garner interference, and those values were similar in manual estimation and in grasping. By contrast, Ganel and Goodale (2014) found larger values for variability-based Garner interference in manual estimation than in closed-loop grasping. In the following experiments, we therefore tried to further scrutinize whether Garner interference is present in manual estimation.

Experiment 2: Manual Estimation With More Trials and Different Block Sequence

The results for manual estimation obtained in Experiment 1 differed from those of Ganel and Goodale (2003, 2014). We therefore made a second replication attempt, where we focused exclusively on manual estimation. This allowed us to increase the number of trials per participant considerably (from 128 to 256 trials), thereby increasing statistical power. We also speculated that a different

Table 2
Variability of Grip Aperture (in Millimeters) for Experiment 1

Task	Baseline	Filtering	Difference	$t(23)$	p	d_z	BF_{10}
Closed-loop grasping	3.34 ± 0.31	3.62 ± 0.26	0.29 ± 0.17	1.72	.050	0.35	1.42
Open-loop grasping	3.67 ± 0.25	3.93 ± 0.36	0.27 ± 0.30	0.90	.188	0.18	0.49
Manual estimation	2.78 ± 0.15	2.99 ± 0.21	0.21 ± 0.15	1.42	.084	0.29	0.92

Note. Values are reported as mean ± standard error of the mean. BF = Bayes factor.

sequence of baseline/filtering blocks might increase Garner interference (see the Methods section).

Method

In total, 24 new right-handed participants (17 women, six men, and one nonbinary person, $M_{age} = 24.3$ years, age range = 19–48) were recruited for this experiment. The experiment consisted of only the manual estimation task and was almost identical to Experiment 1 (we describe only differences to Experiment 1 here). We doubled the number of trials to 256 trials to increase precision, such that the total number of blocks increased to eight, presented in counterbalanced, alternating sequences of BFBFBFBF or FBFBFBFB (with B: baseline and F: filtering condition). This alternating block sequence differed from Experiment 1, where we used counterbalanced sequences of repeated blocks (BBFF or FFBB). We made this change because we assumed Ganel and Goodale (2003) might have also used a sequence of alternating blocks (their article did not specify this). However, during the review process, we learned that Ganel and Goodale (2003) had used the same repeated-block sequence as we had used in Experiment 1. Nevertheless, both sequences have been used frequently (e.g., repeated-blocks sequences were used by: Eloka et al., 2015; Janczyk et al., 2010; Janczyk & Kunde, 2010, 2016; Kunde et al., 2007; Schum et al., 2012; and alternating sequences were used by: Hesse & Schenk, 2013; Löhr-Limpens et al., 2020). Comparing the results of our Experiments 1 and 2 will show that the type of the sequence does not seem to make a big difference.

Data collection took place in 2022. This experiment was not separately preregistered because we followed the same specifications as in Experiment 1. Outliers and exclusion criteria were also identical to Experiment 1 and led to the exclusion of 5% trials overall (including them made no difference to the results). The power to find Garner Interference in manual estimation was about $1 - \beta = .89$ (see the Appendix).

Results

The RT and ManEstTime for baseline and filtering conditions are depicted in Figure 3, bottom panel. The RT, MT, ManEstTime, and SD_{ManEst} results are also listed in Table 3, along with the Garner interference effects.

The Garner interference effect in manual estimation in RT was 8 ± 4 ms (depicted also in Figure 6 in our later literature review). A comparison to Experiment 1 (Tables 1–3) shows that the effects were numerically similar and that the larger number of trials successfully yielded more precise measurement. In consequence, the Garner interference effect in manual estimation was less variable and statistically significant. Nevertheless, it was much smaller than previously reported in the literature (see the Discussion section and Figure 6).

For the Bayesian comparison to test whether Garner interference in manual estimation is more similar to grasping (H_1) than to speeded classification (H_0), we used the grasping and speeded-classification results from Experiment 1 as priors because Experiment 2 (and Experiments 3 and 4) involved only manual estimation (see the Method section of Experiment 1 for details). This yielded a $BF_{10} = 10.5$, which presents strong evidence that Garner interference in manual estimation is more similar to grasping than to speeded classification.

Garner interference was 8 ± 7 ms in MT and 17 ± 9 ms in ManEstTime, much smaller than in Experiment 1. There was now also a significant variability-based Garner interference effect in the ManEst. The height–width illusion effect for the baseline condition was −0.65 ± 0.44 mm, $t(23) = -1.5$, $p = .925$, $d_z = -0.30$, $BF_{10} = 0.10$, and for the filtering condition 0.76 ± 0.18 mm, $t(23) = 4.33$, $p < .001$, $d_z = 0.88$, $BF_{10} = 243$.

Discussion

While previous studies by Ganel and Goodale (2003, 2014) found Garner interference for RTs in a manual estimation task, our first replication attempt (Experiment 1) could not corroborate this and yielded only very small Garner interference (5 ± 13 ms). Experiment 2 was therefore a second replication attempt with more statistical power. But again, we observed only very small Garner interference (8 ± 4 ms), which was numerically much smaller than the 31 ± 13 ms and 22 ± 10 ms effects reported by Ganel and Goodale (2003, 2014), respectively. Furthermore, the Bayesian comparison revealed strong evidence that Garner interference in manual estimation is more similar to grasping than to speeded classification.

Regarding ManEstTime, the results are mixed. In Experiment 1, we found a numerically large (42 ± 25 ms) Garner interference in ManEstTime. In Experiment 2, this was much smaller (17 ± 9 ms). Interestingly, Ganel and Goodale (2003) reported a Garner interference effect in ManEstTime of 48 ± 20 ms, but in their subsequent study (Ganel & Goodale, 2014), no ManEstTime results were reported. However, a reanalysis of the data showed only a small (and not significant) Garner interference effect for this variable (9 ± 13 ms; data were provided via personal communication by Tzvi Ganel). Therefore, it is unclear if Garner interference is to be expected in ManEstTime. Note that one other study with manual estimation (Schum et al., 2012) also did not report a significant Garner interference effect in manual estimation for either variable (RT = −7 ± 8 ms, ManEstTime = 6 ± 38 ms; their footnote 2).

Table 3
Results for Manual Estimation in Experiment 2

Dependent variable (unit)	Baseline	Filtering	Difference	$t(23)$	p	d_z	BF_{10}
RT (ms)	337 ± 16	345 ± 16	8 ± 4	1.99	.029	0.41	2.25
MT (ms)	832 ± 34	840 ± 34	8 ± 7	1.17	.126	0.24	0.66
ManEstTime (ms)	1,169 ± 39	1,185 ± 39	17 ± 9	1.89	.036	0.39	1.88
SD_{ManEst} (mm)	3.53 ± 0.21	3.84 ± 0.19	0.31 ± 0.09	3.38	.001	0.69	35.1

Note. Values are reported as mean ± standard error of the mean. BF = Bayes factor; RT = reaction time; MT = movement time; ManEstTime = time to complete manual estimation; ManEst = manual estimate.

Table 4
Setup and Design Differences in Manual Estimation Across Studies

Parameter	Ganel and Goodale (2003)	Ganel and Goodale (2014)	Experiment 1	Experiment 2
Block sequence	BBFF/FFBB	BBFF/FFBB	BBFF/FFBB	BFBF/FBFB
Task instructions	Speed (?)	Accuracy	Speed + accuracy	Speed + accuracy
Stimulus placement	Horizontal	Vertical	Horizontal	Horizontal
Distance to ManEst	?	25 cm	15 cm	15 cm

Note. "?" represents unknown information that was not provided in the original publication. B = baseline; F = filtering; ManEst = manual estimate.

Even after increasing precision with more trials, the discrepancy between our results in manual estimation and Ganel and Goodale (2003) remained. We therefore searched for differences that could potentially influence the results (see also Figure S1 in the online supplemental materials). We list these differences in Table 4. The block sequence was already mentioned and does not seem to make a difference in the results between Experiments 1 and 2 (compare Tables 1 and 3). Three further issues were identified: task instructions, stimulus placement, and distance to ManEst location.

Regarding task instructions, Ganel and Goodale (2003) emphasized speed in their grasping and speeded-classification tasks but did not explicitly mention the instruction for manual estimation, and presumably, it was also speeded for consistency. Furthermore, since the focus was on RTs, we expect the task to be speeded. Ganel and Goodale (2014) emphasized accuracy. In our own experiments, we asked participants to be as fast and as accurate as possible, thereby striving for a middle ground.

Our stimulus placement was consistent with Ganel and Goodale (2003), with the larger surface area of the cuboids horizontal to the surface of the table (see Figure 1 of Ganel & Goodale, 2003). Ganel and Goodale (2014) instead placed the stimuli vertically (see Figure 2 of Ganel & Goodale, 2014). This was done "to allow subjects to grasp the objects without potentially hitting the surface of the tabletop" (Ganel & Goodale, 2014, p. 4). We do not expect this issue to be a big problem for manual estimation; therefore, it is unlikely to be the reason for our small Garner effects.

Finally, one methodological detail that was missing from Ganel and Goodale (2003) was the distance between the start position and the location where the ManEst was performed. Ganel and Goodale (2014) used 25 cm, while in our Experiments 1 and 2, this distance was 15 cm. There is some evidence that suggests that the movement distance (or amplitude) can influence RTs and Garner interference in RTs (Hesse & Schenk, 2013). This might cause a Garner effect in manual estimation to be masked depending on the setup. In the following experiments, we varied the movement amplitude in manual estimation to investigate if it can modulate the Garner interference effect and explain our results.

Experiment 3: Manual Estimation With Short Versus Long Decision Amplitude

Experiments 1 and 2 attempted to replicate Garner interference in manual estimation. Contrary to previous reports, and to our expectations, we observed only very small values of Garner interference in RTs in Experiments 1 and 2. In an effort to resolve this empirical inconsistency, we explored possible reasons for a modulation of Garner interference in Experiment 3. For example, Ganel and Goodale (2003) did not report the distance between their start button and the location where participants indicated their ManEst. This means that there might have been a difference between our setup and that of Ganel and Goodale (2003) regarding this distance. Below, we describe how and why this difference might explain smaller Garner interference in our manual estimation task.

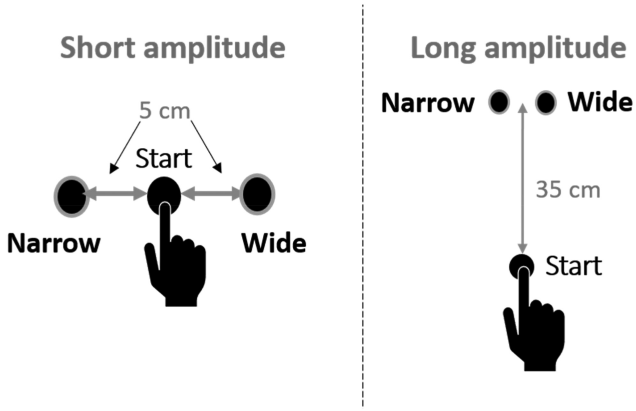
Garner Interference in RT May Depend on Decision Amplitude

Hesse and Schenk (2013) had argued that Garner interference, especially in RTs and regardless of the task, may depend on and be modulated by the temporal profile of the response. Put simply, the presence or absence of Garner interference is determined by whether RT includes the decision time or not. In the perceptual speeded-classification task, participants can only press the appropriate button once a decision has been reached; therefore, RT includes the decision time. However, in grasping (and likely in manual estimation as well), RT is measured at movement onset, but the decision about narrow/wide may occur later during the movement because it is not required for movement onset. Therefore, RT does not necessarily include the decision time. In sum, if the participant's decision occurs before movement onset, RTs will show Garner interference. However, if the task allows participants to delay their decision until after movement onset, RTs will not show Garner interference.

To test this, Hesse and Schenk (2013) manipulated the temporal profile by placing a start button either at a short (5 cm) or long distance (35 cm) from the response (wide/narrow) buttons (see Figure 4) in speeded classification. It was hypothesized that participants will have sufficient time after movement onset in the long amplitude condition, such that they will delay the decision to after releasing the start button. If this were true, the measured RT will not include decision time, and Garner interference will not occur. On the other hand, there would not be sufficient time after movement onset in the short amplitude condition, such that participants are likely to make the decision before moving and RTs will include decision time and show Garner interference. The results supported this hypothesis and showed a clear dissociation: Garner interference was observed in the short amplitude condition, but Garner interference was not significant in the long amplitude condition of the same speeded-classification task that is assumed to be ventrally processed.

For grasping, they reasoned that open-loop conditions (i.e., without visual feedback after movement onset) would force participants to make their decision before movement onset, as no feedback would be further available. Interestingly, they observed (small) Garner interference for open-loop grasping (contrary to Ganel & Goodale, 2003, supplementary material and our Experiment 1).

Figure 4
Illustration of the Setup Used by Hesse and Schenk (2013)

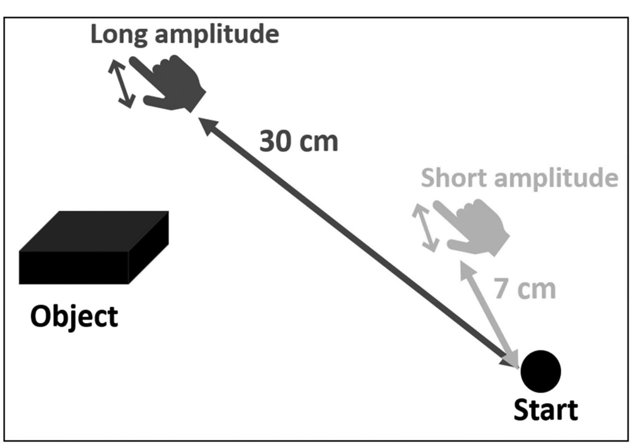


Note. The short and long amplitude conditions of Hesse and Schenk (2013). The decision amplitude determines the amount of time available to make the decision about the object's width.

Overall, Hesse and Schenk (2013) showed that Garner interference in RTs could be induced or reduced within the same task, further questioning the mapping of holistic versus analytic processing to ventral versus dorsal processing.

Critically, Hesse and Schenk (2013) did not include manual estimation in their study. We here applied and extended their approach to manual estimation, to investigate whether Garner interference in this task might also be influenced by the decision amplitude. In our design, we created long and short amplitude conditions by changing the distance between the start button and the position where the width estimate was to be indicated (see Figure 5). The idea was to allow insufficient time between leaving the start button and indicating the ManEst in the short amplitude condition, thereby forcing participants to make their decision before movement onset. This should induce Garner interference in RTs. On the other hand, in the long amplitude condition, there should be sufficient time during the movement to the location of manual estimation and, accordingly, participants can delay their decision to after movement onset.

Figure 5
Illustration of the Setup Used in Experiment 3



Note. The long and short amplitude conditions for manual estimation in Experiment 3 following Hesse and Schenk (2013). The time provided for making a decision was manipulated by varying the amplitude, that is, by changing the distance between the start button and the location where participants indicated their estimate of the object's width.

Method

Transparency and Openness

This experiment was preregistered (https://aspredicted.org/RFF_ZRR). Data collection for this experiment took place in 2022–2023.

Participants and Power Analysis

In total, 34 new participants performed the experiment but two were excluded: one participant was left handed but took part in the experiment for a research seminar and was excluded a priori, and one further participant failed to understand the task (during and after the experiment they posed questions to the experimenter about how to perform the task; results were almost identical even with the data of these two participants). Therefore, the data of 32 right-handed participants (25 women and seven men, $M_{\text{age}} = 22.7$ years, age range = 18–27) were analyzed. The critical effect we wanted to investigate is a modulation of Garner interference in RTs by amplitude (i.e., larger Garner interference in the short amplitude condition than in the long amplitude condition). For this comparison, we estimated the power to be at least $1 - \beta = .79$ (cf. the Appendix). All other details regarding ethics, consent, and compensation were identical to Experiment 1.

Stimuli, Apparatus, and Procedure

Only the manual estimation task was used, and stimuli and apparatus were identical to Experiments 1 and 2. Participants performed four combinations of conditions: long-baseline, long-filtering, short-baseline, and short-filtering. The order of the conditions was counterbalanced and alternated. Participants performed four blocks (BFBF or FBFB) of one amplitude, and then four blocks of the other amplitude. Thus, the Garner condition as well as amplitude was counterbalanced. Participants performed eight blocks in total and each block consisted of 48 trials, resulting in 384 trials overall. Participants were instructed to be as accurate and fast as possible. In the long condition, participants estimated the width of the objects at a distance of 30 cm from the start position. In the short condition, this distance was 7 cm (see Figure 5). Hesse and Schenk (2013) used 5 cm for their short condition in a speeded-classification task. We slightly increased this distance to 7 cm because it seemed more comfortable for manual estimation during the piloting phase, with the expectation that a distance of 5 cm versus 7 cm would not lead to differences when compared to 30 cm. Regardless, in Experiment 4, we conducted also a short condition with 3 cm amplitude with essentially the same results (see below).

As in Experiments 1 and 2 and other studies (Ganel & Goodale, 2003, 2014; Hesse & Schenk, 2013), we used a velocity threshold to determine movement onset and RT. Brenner and Smeets (2019) suggested that using a velocity threshold can lead to different RTs depending on the amplitude of the movement (longer RTs for shorter movements). The same is true when using a button, which was the method employed by Hesse and Schenk (2013) for their speeded-classification task. To rule out any confounds due to this methodological choice, we additionally calculated RTs with very high and very low velocity thresholds. Our results are essentially similar with our standard velocity threshold and the high/low values. The results are reported in Table S2 in the online supplemental materials.

Dependent Variables and Analyses

Trial exclusions were based on the criterion used by Hesse and Schenk (2013): Outliers corresponding to RTs shorter than 100 ms and longer than 2.5 *SD*s above the mean of the participant (in a certain condition) were excluded from the analysis. This led to the exclusion of 2.5% of trials as outliers. Pilot experiments revealed that there was large within-participant variability in the time-based measures; therefore, a further exclusion criterion was used (and preregistered): Trials with MT and/or ManEstTime beyond the $M \pm 2$ *SD*s for each participant (in a certain condition) were also excluded from the analysis. However, this criterion was not used by Ganel and Goodale (2003, 2014) and might decrease the comparability of our results. For transparency, we report the results with our criterion in Table S3 in the online supplemental materials but report results without this criterion below. We used the same dependent variables as described in Experiment 1 for manual estimation: RT, MT, ManEstTime, and variability. We performed separate ANOVAs with the factors condition (baseline, filtering) and amplitude (long, short) as repeated-measures on these variables. We also performed the Bayesian comparison on RTs in a similar way as Experiments 1 and 2.

Results

RTs

The Garner interference effects are provided in Table 5 and depicted also in Figure 6. The ANOVA for RT resulted in a NonsSignificant Condition × Amplitude Interaction, $F(1, 31) < 0.01$, $p = .974$, $\eta^2_G < .01$, and a nonsignificant main effect of Garner condition $F(1, 31) = 1.94$, $p = .174$, $\eta^2_G < .01$. Only the main effect of amplitude was significant, $F(1, 31) = 10.46$, $p = .003$, $\eta^2_G = .04$; therefore, the overall RTs were significantly different for each amplitude condition. For consistency with the power analysis (cf. the Appendix), we also performed a one-tailed *t* test for the difference between Garner interference in RTs of short and long amplitude conditions. As evidenced by a nonsignificant ANOVA interaction, there was no significant difference between the conditions: 0.28 ± 8 ms, $t(31) = 0.03$, $p = .487$, $d_z = 0.01$, $BF_{10} = 0.19$.

A similar result was obtained in MT and ManEstTime: The ANOVAs revealed only a main effect of amplitude on MT, $F(1, 31) = 93.39$, $p < .001$, $\eta^2_G = .15$, and on ManEstTime, $F(1, 31) = 42.04$, $p < .001$, $\eta^2_G = .08$, but there was again no significant main effect of Garner condition, MT: $F(1, 31) = 0.86$, $p = .360$, $\eta^2_G < .01$; ManEstTime: $F(1, 31) = 1.64$, $p = .210$, $\eta^2_G < .01$, nor a significant interaction, MT: $F(1, 31) = 0.11$, $p = .739$, $\eta^2_G < .01$; ManEstTime: $F(1, 31) = 0.07$, $p = .796$, $\eta^2_G < .01$. Thus, we did not find a modulation of Garner interference by amplitude.

The Garner interference effect on RT was 6 ± 6 ms in the short amplitude condition and in the long amplitude condition, it was also 6 ± 6 ms (see Table 5 and Figure 6). Comparing these values to Experiment 1 and 2 shows that the numerical values were very similar between experiments.

For the Bayesian comparison, we pooled the results of manual estimation from the short and long conditions (testing these conditions individually led to similar results because the mean and *SEM* were almost identical). Then, we used the grasping and speeded-classification results from Experiment 1 as priors to calculate Bayes factors to test whether Garner interference in manual estimation is more similar to grasping (H_1) or to speeded classification (H_0). This resulted in a $BF_{10} = 29.5$, which is strong evidence that Garner interference in manual estimation is more similar to grasping than to speeded classification.

Variability

The ANOVA on variability resulted in a main effect of condition, $F(1, 31) = 6.02$, $p = .020$, $\eta^2_G = .02$, but no significant main effect of amplitude, $F(1, 31) = 1.02$, $p = .321$, $\eta^2_G < .01$, or an interaction, $F(1, 31) = 0.60$, $p = .445$, $\eta^2_G < .01$. Variability-based Garner interference in both the long and the short amplitude conditions in Experiment 3 (see Table 5) was in a similar range as the values from Experiments 1 and 2.

Discussion

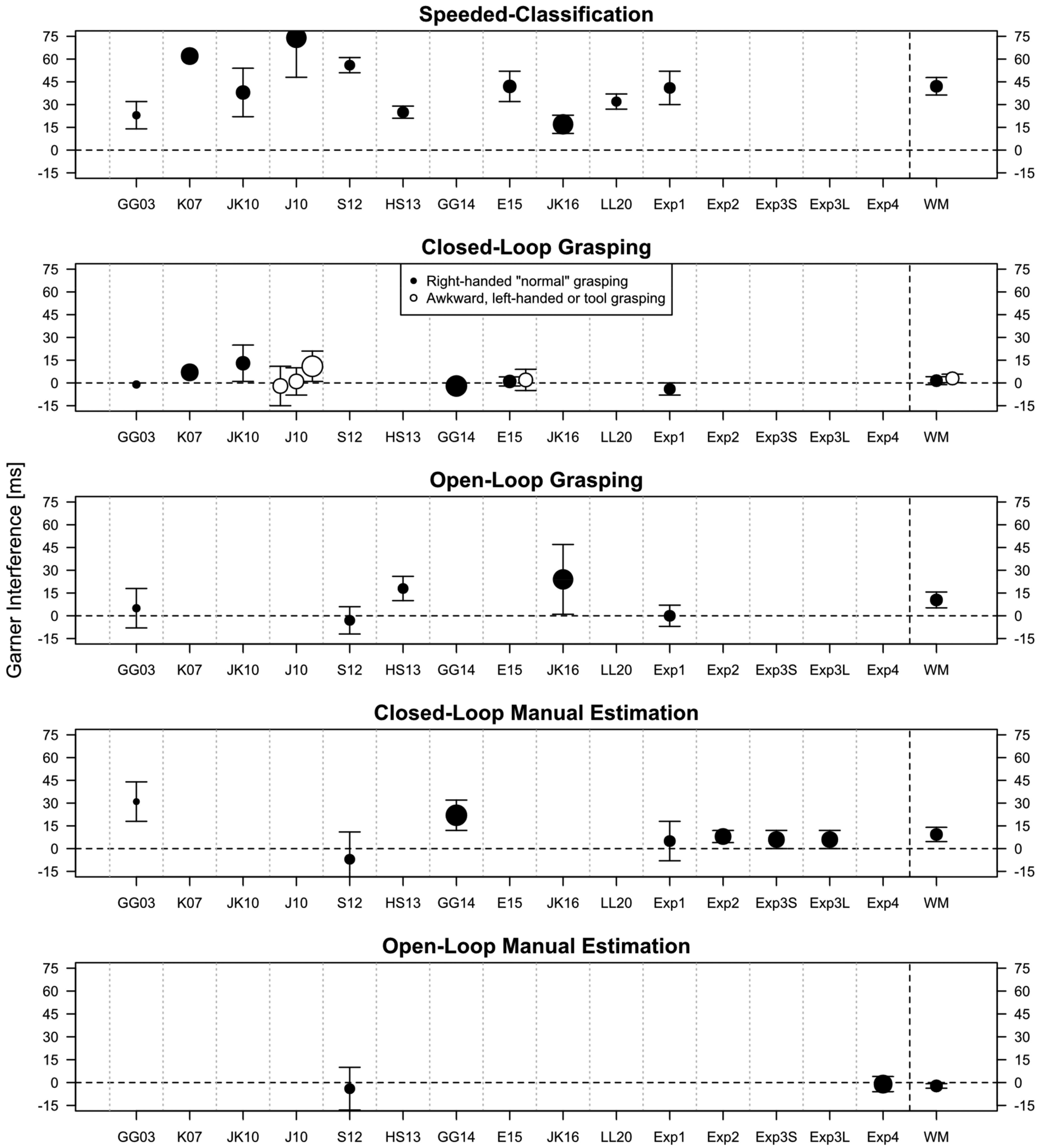
Experiment 3 followed the logic advanced by Hesse and Schenk (2013) and attempted to demonstrate that Garner interference can be modulated by the decision amplitude. Specifically, we expected that only with a short amplitude Garner interference would be observed in the manual estimation task, while with a long decision amplitude, Garner interference would not be visible because RTs in this case do not include the decision time. Thus, we reasoned that the probability

Table 5
Garner Interference Effects for Experiment 3

Dependent variable (unit)	Short			Long		
	Baseline	Filtering	Difference	Baseline	Filtering	Difference
RT (ms)	315 ± 10	321 ± 11	6 ± 6	291 ± 12	297 ± 12	6 ± 6
MT (ms)	661 ± 30	669 ± 29	8 ± 8	811 ± 31	814 ± 33	3 ± 9
ManEstTime (ms)	976 ± 37	990 ± 36	14 ± 12	1,102 ± 39	1,111 ± 40	9 ± 13
SD_{ManEst} (mm)	3.53 ± 0.17	3.88 ± 0.22	0.35 ± 0.16	3.43 ± 0.14	3.65 ± 0.13	0.22 ± 0.12

Note. Values are reported as mean ± standard error of the mean. RT = reaction time; MT = movement time; ManEstTime = time to complete manual estimation; ManEst = manual estimate.

Figure 6
Garner Interference Effects in Reaction Time



Note. The size of the symbol for each study is scaled according to the square root of the product of the sample size and number of trials in that study. Error bars represent ± 1 *SEM*. See Table 8 for study abbreviations. WM = weighted mean; *SEM* = standard error of the mean.

of observing Garner interference should be increased in the condition with the short amplitude. However, neither did we observe overall Garner interference nor was there a significant interaction pointing to the expected modulation by amplitude. However, decision amplitude had an effect on RT, MT, and ManEstTime. This is certainly expected and obvious for MT and ManEstTime because

MT/ManEstTime would strongly depend on the distance to the ManEst location. The notable result is the effect on RT: Participants were faster to respond in the long condition than in the short condition (24 ± 7 ms). These faster responses in the long condition might indicate that participants delay their decision to after movement onset. This result is in line with Hesse and Schenk (2013) and their decision amplitude hypothesis. However, based on these results, we cannot conclude whether the distance/decision amplitude played a role in modulating Garner interference in manual estimation in our Experiments 1 and 2.

Our results on variability-based Garner interference were consistent with Experiments 1 and 2, and additionally, we did not observe an effect of amplitude. Future research should address whether variability-based Garner interference is more robust and immune to effects of decision amplitude than RTs.

Despite our efforts to modulate the Garner interference effect between the short and long conditions, we obtained almost identical results in both conditions, which are also numerically similar to results from Experiments 1 and 2. The Bayesian comparison was also consistent and revealed strong support for the hypothesis that Garner interference in manual estimation is more similar to grasping than to speeded classification.

We conducted the following Experiment 4 as a control to check if our results were due to our short condition (7 cm) being longer than the 5 cm in the study by Hesse and Schenk (2013).

Experiment 4: Open-Loop Manual Estimation and Very Short Decision Amplitude

Our results from Experiment 3 suggest an influence of short versus long response amplitude on the overall RT but not on Garner interference in RTs. One objection to Experiment 3 might be that our short condition had a distance of 7 cm, while the short condition in Hesse and Schenk (2013) was 5 cm. To rule out the possibility of our short condition not being "short enough," we conducted another manual estimation experiment, with only one response amplitude condition of 3 cm, that is, even shorter than 5 cm used by Hesse and Schenk (2013).

In addition, we modified the task to further favor the decision–amplitude hypothesis by testing for Garner interference in an open-loop manual estimation task. This meant that after movement onset, participants no longer had visual feedback about the stimulus. Hesse and Schenk (2013) reported Garner interference in their open-loop grasping task and they reasoned that it was due to the open-loop nature of the task. Because participants knew that they will not have visual feedback after movement onset, they took longer to initiate the movement, thereby causing the Garner interference effect in RT (time until movement onset). There is only one other study (Schum et al., 2012) that actually investigated Garner interference in open-loop manual estimation but their result was not significant (−4 ± 14 ms), so there is an urgent need for more data on this task.

Finally, we also included an additional Garner condition in the experiment, called the correlated condition. This condition was part of Garner's original experiments and required two additional blocks: one with stimuli A and D, the other with stimuli B and C (see Figure 1). The idea is that the length and width of the stimuli within a block are either positively (B and C) or negatively correlated (A and D), such that one dimension can predict the other. Therefore, if length and width cannot be independently processed and correlated with each other, knowing one will facilitate the classification of the other. Accordingly, a comparison of the RTs in the baseline and correlated conditions shows that participants are faster in the correlated condition for integral dimensions (Garner, 1974). We will call this RT difference the Garner facilitation effect (= baseline − correlated). Our reasoning for using this additional condition is the following: if it is somewhat inconclusive whether or not there is a Garner interference effect in manual estimation that is larger than in grasping, then alternative evidence may be provided by demonstrating a clear Garner facilitation effect. Furthermore, it addresses the issue of presenting differing numbers of stimuli between the baseline and filtering conditions, two stimuli per block in baseline and four stimuli per block in filtering conditions (see also Dyson & Quinlan, 2010; Janczyk & Kunde, 2012). In the correlated condition, there are also two stimuli presented per block, thus making it more comparable to the baseline condition. To our knowledge, no other study tested for Garner facilitation in manual estimation, while one study (Eloka et al., 2015) tested it in grasping (closed loop) and found a nonsignificant effect (−5 ± 4 ms).

Therefore, in this experiment, we performed two modifications that should favor the occurrence of Garner interference and included an additional condition that should allow us to test for alternative evidence for a dissociation between grasping and manual estimation.

Method

Transparency and Openness

This experiment was preregistered at AsPredicted (https://aspredicted.org/VC3_2T4). Data collection took place in 2023–2024 and began before the preregistration (for details see preregistration). We have preregistered this experiment for consistency with the other experiments and to control for optional stopping by setting the final sample size comparable to Experiment 3.

Participants

In total, 32 new participants performed the experiment. Two were excluded a priori (one was left handed and the other ambidextrous) but were allowed to participate nevertheless as part of a research seminar (results were similar even when including these data). Therefore, the data of 30 right-handed participants (17 women and 13 men, $M_{age} = 22$ years, age range = 19–30) were analyzed. We aimed to collect 30 participants so that the sample size was comparable to Experiment 3 and to have balanced groups (six groups resulting from counterbalancing, see below).

Stimuli, Apparatus, and Procedure

The experiment consisted of only manual estimation. Stimuli and apparatus were identical to Experiments 1–3. Participants performed three conditions: baseline, filtering, and correlated. The order of the conditions was fully counterbalanced and alternated (resulting in six possible orders). Participants performed 12 blocks in total and each block consisted of 32 trials, resulting in 384 trials overall. Participants performed manual estimation at a distance of 3 cm from the start position. In contrast to Experiments 1–3, the shutter goggles turned opaque at movement onset, and no visual feedback was further available (open-loop manual estimation). One small change in the stimuli compared to the previous experiments was that a 5-mm thick felt padding was glued to the bottom of the rectangular cuboids. This dampened the sound made when they were placed on a surface, which may serve as a warning for participants that the trial is about to begin.

Dependent Variables and Analyses

Most analyses were identical to Experiment 2. We additionally calculated the Garner facilitation effect by taking the difference between the baseline and correlated conditions. Outliers were determined in the same way as Experiments 1 and 2 and 4% of trials were thus excluded.

Results

The RT, MT, ManEstTime, and variability of ManEst are provided in Table 6. The Garner effects are listed in Table 7 and depicted in Figure 6. Participants' RTs increased slightly from Experiments 1–3, likely because of the open-loop nature of the task. The MTs decreased in comparison with Experiment 3 because the response amplitude for the ManEst was now even shorter (3 cm instead of 7 cm) so participants needed less time to move this shorter distance.

We did not find a significant Garner interference or Garner facilitation effect in RT, the most important variable. The situation is similar for ManEstTime and variability of ManEst. But for MT, we found a small and significant Garner interference effect of 7 ms. The Garner facilitation effect in MT was similar in magnitude but did not reach significance.

For the Bayesian comparison to test whether Garner interference in open-loop manual estimation is more similar to open-loop grasping (H_1) than to speeded classification (H_0), we used the open-loop grasping and speeded-classification results from Experiment 1 as priors because Experiment 4 involved only manual estimation (see the Method section of Experiment 1 for details). This yielded a $BF_{10} = 638.5$, which presents strong evidence that Garner interference in open-loop manual estimation is more similar to open-loop grasping than to speeded classification.

Discussion

Experiment 4 was conducted to rule out that Garner effects may have been missed because the short amplitude condition in Experiment 3 was not short enough. Therefore, we decreased the amplitude of the short condition to 3 cm in Experiment 4. We also made manual estimation task open loop and included a correlated condition to check for Garner facilitation effects. All these changes were expected to favor and increase the likelihood of occurrence of Garner effects. The results indicate that the shorter response amplitude and open-loop conditions slightly increased the RT (compared to the previous experiments), but there was still no significant Garner effect—neither interference nor facilitation. The Bayesian comparison instead revealed strong support for the hypothesis that Garner interference in open-loop manual estimation is more similar to open-loop grasping than to speeded classification.

In Experiments 1–3, variability-based Garner interference seemed promising and robust enough to detect in manual estimation, but it was not significant in the present experiment. Since there were as many trials and even more participants in Experiment 4 than Experiment 2, we expect there to be sufficient precision to detect an effect as large as in Experiment 2.

Finally, there was a small but significant Garner interference effect in MTs. None of the other results or studies found such an effect on MTs. As explained in Experiment 1, MT is a better measure of Garner interference than ManEstTime because it is independent from RT. Further research and more data are required to confirm this effect.

Table 6
Results of Experiment 4 in Baseline, Filtering, and Correlated Conditions

Dependent variable (unit)	Correlated	Baseline	Filtering
RT (ms)	395 ± 16	401 ± 17	400 ± 15
MT (ms)	577 ± 24	584 ± 25	591 ± 26
ManEstTime (ms)	972 ± 34	985 ± 37	991 ± 36
SD_{ManEst} (mm)	4.40 ± 0.26	4.37 ± 0.21	4.47 ± 0.21

Note. Values are reported as mean ± standard error of the mean. RT = reaction time; MT = movement time; ManEstTime = time to complete manual estimation; ManEst = manual estimate.

Comprehensive Literature Review

Two studies reported large effects of Garner interference in manual estimation RTs (31 ± 13 ms, Ganel & Goodale, 2003; 22 ± 10 ms, Ganel & Goodale, 2014), but we found much smaller effects across the four experiments reported here. In the present section, we aim to resolve this empirical inconsistency with a comprehensive and quantitative literature review. Many studies measured Garner interference for speeded classification and grasping, and although they did not include manual estimation, compiling the results across these different tasks and studies may allow us to better estimate these effects (Spence & Stanley, 2024; Stanley & Spence, 2014). In addition to looking at effects from each individual study, we also compute weighted averages across all studies to get an estimate of the effect based on all the currently available data.

Method

Study Selection and Data Availability

Based on a literature review, we identified those studies that investigated Garner interference and were comparable to the very first study on this topic by Ganel and Goodale (2003): Eloka et al. (2015), Ganel and Goodale (2014), Hesse and Schenk (2013), Janczyk et al. (2010), Janczyk and Kunde (2010, 2016), Kunde et al. (2007), Löhr-Limpens et al. (2020), and Schum et al. (2012). The following studies were excluded: Janczyk and Kunde (2012) because they did not have a baseline and filtering condition separately, and Freud and Ganel (2015) and the grasping task of Löhr-Limpens et al. (2020) because they presented two-dimensional (2D) objects (this is controversial for Löhr-Limpens et al., 2020; see Ganel et al., 2020). Summary statistics reported in the original publications and values from plots (digitized wherever possible) were used to calculate Garner interference from Ganel and Goodale (2003, 2014) and Kunde et al. (2007). Tzvi Ganel and Constanze Hesse kindly provided partial data from Ganel and Goodale (2003, 2014) and Hesse and Schenk (2013) via personal communication, respectively. The full data from the following studies were available through Markus Janczyk and Volker H. Franz who were coauthors

Table 7
Garner Effects and Results of Paired One-Tailed t Tests in Experiment 4

DV (unit)	Facilitation					Interference				
	$M \pm SEM$	$t(29)$	p	d_z	BF_{10}	$M \pm SEM$	$t(29)$	p	d_z	BF_{10}
RT (ms)	6 ± 6	0.98	.168	0.18	0.50	-1 ± 5	−0.27	.607	−0.05	0.16
MT (ms)	7 ± 6	1.18	.123	0.22	0.64	7 ± 4	1.90	.034	0.35	1.81
ManEstTime (ms)	13 ± 11	1.17	.125	0.21	0.63	6 ± 7	0.94	.179	0.17	0.47
SD_{ManEst} (mm)	-0.02 ± 0.16	−0.14	.554	−0.02	0.18	0.09 ± 0.14	0.68	.252	0.12	0.36

Note. DV = dependent variable; Facilitation = baseline − correlated; Interference = filtering − baseline; *SEM* = standard error of the mean; BF = Bayes factor; RT = reaction time; MT = movement time; ManEstTime = time to complete manual estimation; ManEst = manual estimate.

on these studies: Eloka et al. (2015), Janczyk et al. (2010), Janczyk and Kunde (2010, 2016), and Schum et al. (2012). The data of Löhr-Limpens et al. (2020) were openly available. The details for each study are listed in Table 8.

Dependent Variables and Analyses

We focused on the dependent variables most commonly reported and deemed important and of interest by previous studies. Our analyses therefore included RT (or time to initiate movement), the most often reported dependent variable. For manual estimation, the ManEstTime (see Experiment 1) was reported by Ganel and Goodale (2003) and Schum et al. (2012). We therefore also analyzed this measure and used the MGATime as the analogous variable in grasping. Further, we analyzed the variability-based Garner interference in MGA/ManEst and calculated the height–width illusion effect. We calculated SEMs where possible. In addition, we calculated the weighted mean for each dependent variable across the different studies. The weights were determined by the sample size of those studies. Because the *SEM* for each individual study was not always available, the *SEM* of the weighted mean was calculated by taking the standard error of the (nonweighted) means of all the studies.

Results

The data presented here comprise two parts: (a) results from studies on Garner interference and (b) completely new analyses of published data (e.g., variability-based Garner interference and the height–width illusion were not originally reported by many studies). Figures 6–9 depict an overview of the results. Numerical values of the overall Garner interference effects from the figures are also listed in Table 9.

Most studies analyzed RTs, and therefore, we have many data points for this variable available. Comparing the weighted means (Table 9 and Figure 6), it seems clear that speeded classification has a large effect which is far larger than in grasping and manual estimation, which have a much smaller effect. Furthermore, the open symbols in Figure 6 represent unusual cases of grasping where the PAM predicts a Garner interference effect due to ventral intrusions (see the General Discussion section). The weighted means, however, suggest that the effect is similar to cases of “normal” grasping, and is close to zero.

For MGATime/ManEstTime, the picture is unclear. Considering manual estimation, some studies that found a large value (GG03 and our Experiment 1, see Figure 7) could not replicate their own finding when methods were improved (GG14 and our Experiment

Table 8
Sample Size and Number of Trials in Studies on Garner Interference

Study	Code	Speeded classific.		Closed loop				Open loop			
				Grasp		ManEst		Grasp		ManEst	
		N	K	N	K	N	K	N	K	N	K
Ganel and Goodale (2003)	GG03	12	128	12	128	8	128	12	128		
Kunde et al. (2007)	K07	24	288	24	288						
Janczyk and Kunde (2010)	JK10	16	288	16	288						
Janczyk et al. (2010)	J10	32	288								
Schum et al. (2012)	S12	20	128			20	128	20	128	20	128
Hesse and Schenk (2013)	HS13	24	128					20	128		
Ganel and Goodale (2014)	GG14			40	256	40	256				
Eloka et al. (2015)	E15	24	168	24	168						
Janczyk and Kunde (2016)	JK16	32	288								
Löhr-Limpens et al. (2020)	LL20	24	96								
Experiment 1	Exp1	24	128	24	128	24	128	24	128		
Experiment 2	Exp2					24	256				
Experiment 3 Short	Exp3S					32	192				
Experiment 3 Long	Exp3L					32	192				
Experiment 4	Exp4									30	256

Note. Code represents the abbreviation used in the *x* axes of Figures 6–9. Classific. = classification; ManEst = manual estimation; *N* = number of participants; *K* = number of trials in total (baseline + filtering).

Table 9
Weighted Means ± SEM for Garner Interference in Different Dependent Variables

		Closed loop		Open loop	
Dependent variable (unit)	SC	Grasp	ManEst	Grasp	ManEst
RT (ms)	42 ± 6	2 ± 3	9 ± 5	10 ± 5	−2 ± 2
MGA/ManEstTime (ms)		−3 ± 2	17 ± 6	4 ± 9	−6 ± 16
Variability (mm)		0.10 ± 0.06	0.35 ± 0.06	0.46 ± 0.13	0.16 ± 0.09

Note. SEM = standard error of the mean; SC = speeded classification; ManEst = manual estimation; RT = reaction time; MGA = maximum grip aperture; ManEstTime = time to complete manual estimation.

2, see Figure 7) and the subsequent result was much smaller, even though the subsequent study was conducted by the same authors. However, it must first be resolved whether Garner interference should be expected in ManEstTime at all.

Variability-based Garner interference was introduced only later by Ganel and Goodale (2014). Here, we find differences between closed- and open-loop conditions: there seems to be a difference between closed-loop grasping and manual estimation, but the difference is in the opposite direction in open-loop conditions (see Table 9 and Figure 8).

For the height–width illusion, we have even fewer data points available (see Figure 9). Therefore, the weighted means are not very informative. Ganel and Goodale (2003) reported the height–width illusion effect for the filtering condition only. For completeness, we depict in Figure 9 baseline and filtering conditions separately.

Discussion

We performed a literature review and compiled the results to give an overview of Garner interference in different tasks and dependent variables for all studies on this topic. Let us first summarize the findings at the level of the overall effects (i.e., weighted means).

The most important dependent variable is RT (because this is the variable that can be measured in all tasks, cf. Figure 6). For speeded classification, results are very consistent: There is a clear Garner interference effect on RTs. For manual estimation, however, there is overall hardly any Garner interference on RTs and—most importantly—those effects are similar to the Garner interference effects found in grasping. This suggests that manual estimation and grasping may be more similar than often assumed.

For MGATime/ManEstTime (Figure 7), the Garner interference effects in manual estimation seem so unreliable that they could not be replicated even by the same authors (compare GG03–GG14). Therefore, future research should clarify whether ManEstTime is a variable of interest for Garner interference. Also, it would need to be clarified whether ManEstTime (measured at the time of the manual estimation) is functionally comparable to an MGATime in grasping (measured at the time of MGA).

Variability-based Garner interference effects (Figure 8) show an interesting reversal: It seems larger in closed-loop manual estimation than in closed-loop grasping, while the opposite seems to be the case for open-loop manual estimation (i.e., smaller Garner interference than in open-loop grasping).

Testing for the height–width illusion (Figure 9) shows quite variable effects, such that the results are difficult to interpret. For example, the largest measured effect was in the baseline condition of open-loop grasping (cf. data point GG03) and not in manual estimation. Future research should clarify how baseline and filtering conditions should be taken into account (e.g., Ganel & Goodale, 2003 analyzed only the filtering condition but did not give a rationale why one should ignore the baseline condition). Finally, none of the studies made a direct comparison between grasping, manual estimation, and a classic perceptual task—which would be a good reference for such research (e.g., Franz & Gegenfurtner, 2008).

All in all, the data from all studies currently available on Garner interference in the context of the PAM show a small difference in some dependent variables but do not provide consistent or convincing evidence for differences in manual estimation and grasping. These differences are even smaller when considering open-loop grasping. Open-loop grasping versus closed-loop manual estimation may be an unfair comparison, but the dorsal versus ventral assumption still applies here, and some studies even argued that open-loop conditions provide a stronger test case for the PAM (Haffenden & Goodale, 1998; Post & Welch, 1996). Furthermore, the literature review also revealed that, while there are equally many studies investigating closed-loop and open-loop grasping, there are only two studies (including the present one) that investigated open-loop manual estimation, and future research should fill this empirical gap. This is all the more important because our literature review suggests that there is a different pattern of results in some dependent variables between open-loop and closed-loop manual estimation, but the PAM is silent about whether open-loop versus closed-loop tasks are processed differently.

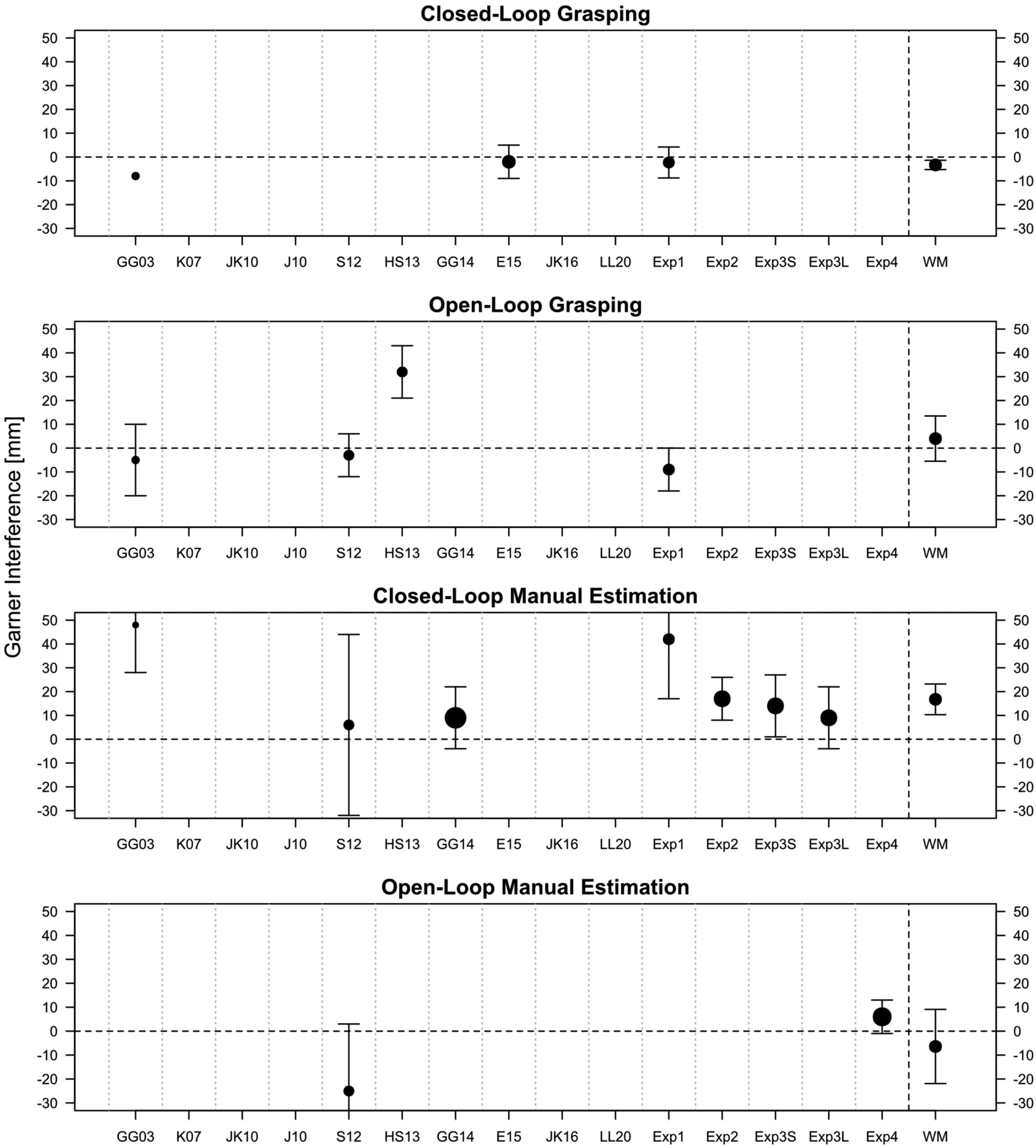
General Discussion

The presence of Garner interference in manual estimation and its absence in grasping has been used as evidence for the PAM (Goodale & Milner, 1992), the notion that the dorsal and ventral stream process visual information independently and differently for action and perception, respectively (Ganel & Goodale, 2003, 2014). However, the empirical results for manual estimation are quite unclear. This crucial and important comparison task lacks widespread and convincing empirical support. The goal of the present study was to add to the discussion with improved replications of the original study on this topic (Ganel & Goodale, 2003).

Is There Garner Interference in Manual Estimation?

The central question posed here was: Is there Garner interference in manual estimation? Manual estimation is a task assumed to have comparable demands as grasping; therefore, this comparison is the most appropriate test for the PAM (rather than comparing grasping with speeded classification). Reviewing the literature revealed that Garner interference in manual estimation has not often been replicated, and one study even observed a nonsignificant negative effect (Schum et al., 2012).

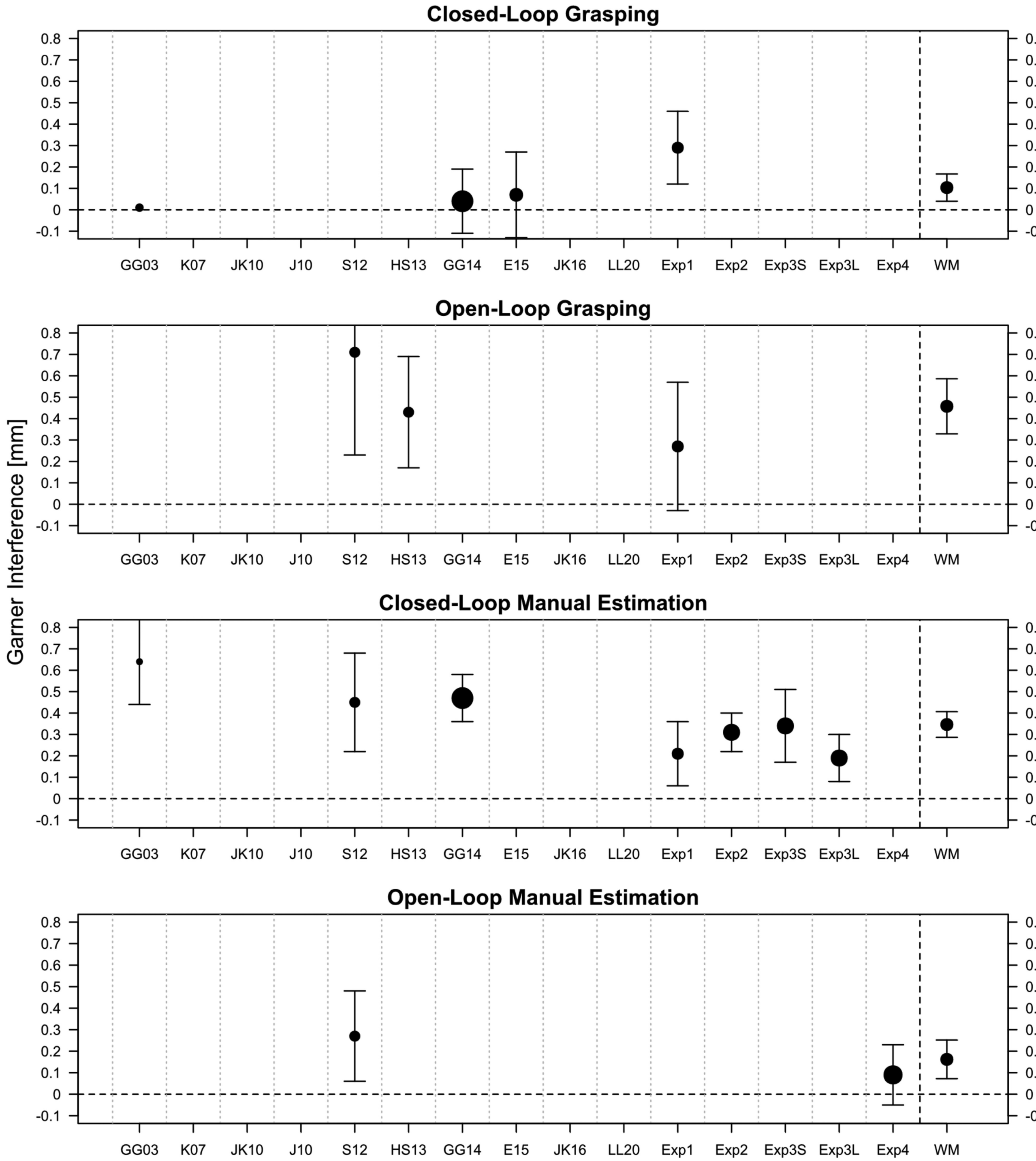
Figure 7
Garner Interference Effects in MGATime/ManEstTime



Note. Garner interference in MGATime for grasping and ManEstTime for manual estimation. The size of the symbol for each study is scaled according to the square root of the product of the sample size and number of trials in that study. Error bars represent ± 1 *SEM*. See Table 8 for study abbreviations. MGATime = time point at which the maximum grip aperture occurred; ManEstTime = time to complete manual estimation; WM = weighted mean; *SEM* = standard error of the mean.

The main focus of our investigation was RT, as it is the most frequently reported dependent variable. For other variables, the results did not show a clear consensus. In Experiments 1 and 2, we tried to replicate Ganel and Goodale (2003, 2014) and were able to observe the typical results of large Garner interference in speeded classification and small, nonsignificant Garner

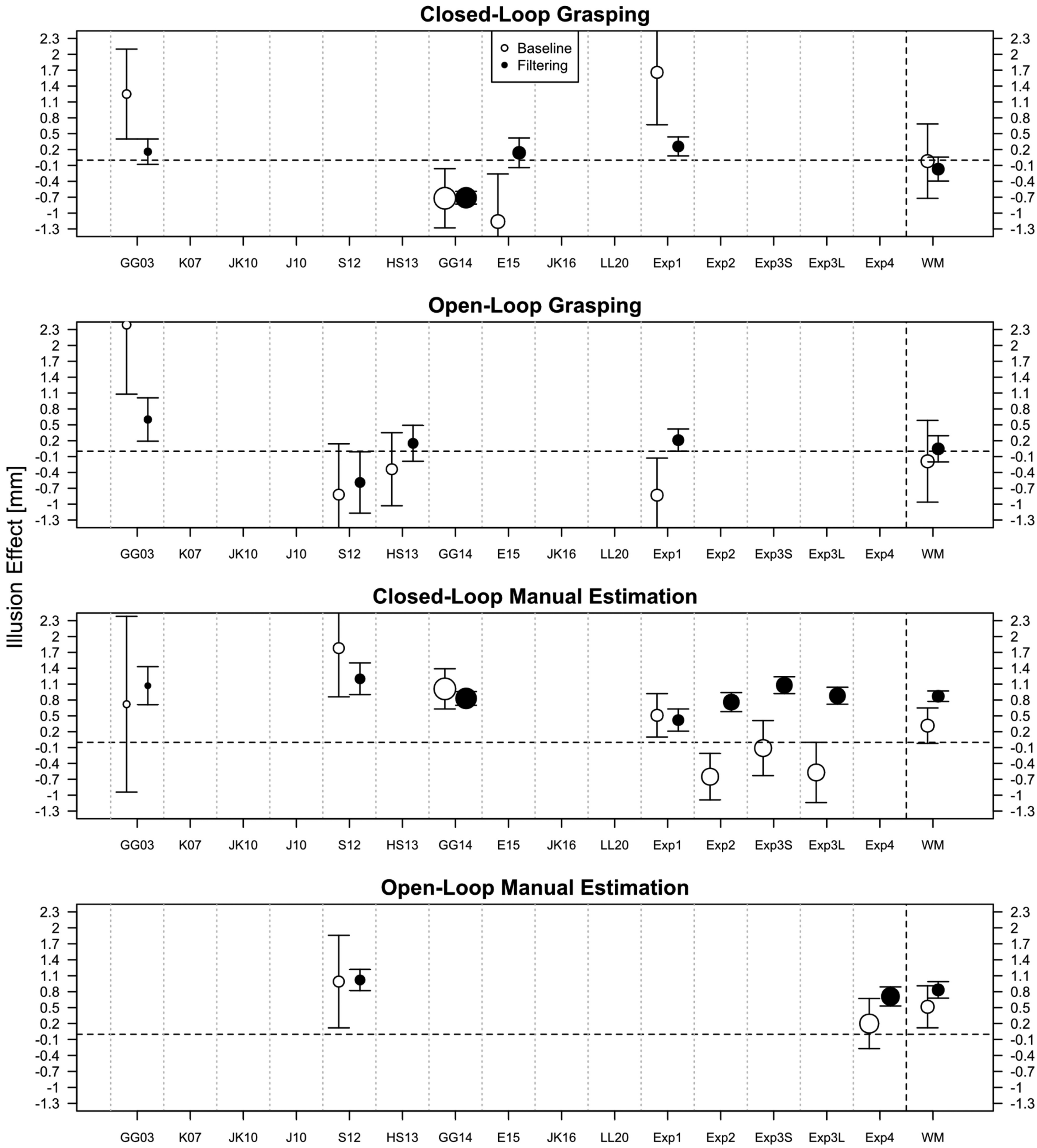
Figure 8
Variability-Based Garner Interference Effects



Note. Garner interference in the variability (within-participant standard deviation) of grasping (MGA) and manual estimation (ManEst). The size of the symbol for each study is scaled according to the square root of the product of the sample size and number of trials in that study. Error bars represent ± 1 *SEM*. See Table 8 for study abbreviations. WM = weighted mean; MGA = maximum grip aperture; ManEst = manual estimate; *SEM* = standard error of the mean.

interference in grasping. However, we did not conclusively observe Garner interference in manual estimation in Experiments 1 and 2, and the descriptive size of Garner interference was <10 ms, which is much smaller than the 20–30 ms Garner interference reported in previous studies (Ganel & Goodale, 2003, 2014). These results suggest that the Garner interference in RTs of manual

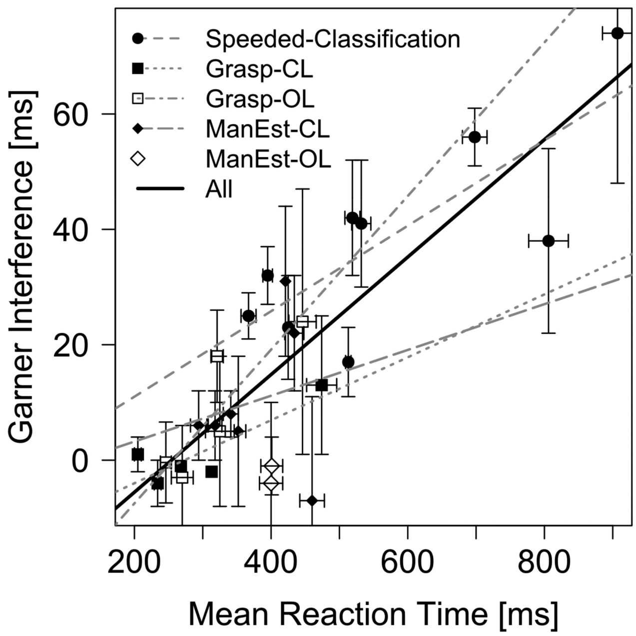
Figure 9
Height–Width Illusion Effects



Note. The size of the symbol for each study is scaled according to the square root of the product of the sample size and number of trials in that study. Error bars represent ± 1 *SEM*. See Table 8 for study abbreviations. WM = weighted mean; *SEM* = standard error of the mean.

estimation, if it is present at all, is rather small (see Figure 6). Further, the Bayesian comparisons resulted in $BF_{10} \geq 10$ across all four experiments, providing substantial-to-strong evidence that the small Garner interference in manual estimation is more similar to the Garner interference in grasping than in speeded classification.

Figure 10
Garner Interference as Function of Mean Reaction Time



Note. Each point represents mean ± standard error of one study from Table 8. Regression lines depicting Garner interference as a function of mean reaction time are plotted for each task individually as well as for all tasks together. No regression line is plotted for open-loop manual estimation since there are only two studies with this task. Error bars represent ±1 *SEM*. CL = closed loop; OL = open loop; ManEst = manual estimation.

Relationship Between Garner Interference and RT

The results of Experiment 1 (Table 1) reveal a relationship that is not entirely unexpected: the magnitude of Garner interference seems to depend on RT. Indeed, plotting RTs as a function of Garner interference (Figure 10) indicates a strong correlation ($r = .83$): the longer the RT in a task, the larger the Garner interference (for a similar issue in the Stroop effect, see Verhaeghen & De Meersman, 1998).

Furthermore, a positive correlation between RT and the size of Garner interference was present for each individual task. This means that Garner interference seems to increase with RT in each task, so larger Garner interference would be expected for longer RTs regardless of whether that task is grasping, manual estimation or speeded classification. In light of this result, the assumption that grasping and manual estimation have similar task demands may not be reasonable. This might be a more parsimonious explanation for some studies reporting differences in Garner interference in these tasks than attributing the processing of these tasks to the dorsal and ventral streams.

Does Decision Amplitude Affect Garner Interference?

To explain our results of very small Garner interference for manual estimation in Experiments 1 and 2, we considered whether the decision amplitude may be modulating the Garner interference effect. Hesse and Schenk (2013) pointed out that the presence or absence of Garner interference in RTs is problematic for evaluating processing differences in tasks because one could modulate Garner interference within the same task by changing time constraints or decision amplitude.

While Hesse and Schenk (2013) demonstrated this only for speeded classification, we extended their reasoning to manual estimation in Experiment 3 and compared a short and long decision amplitude condition. While we did not observe the expected dissociation (Garner interference larger for short condition than for long condition), overall RTs were longer for the short amplitude condition than for the long amplitude condition, suggesting that participants took more time in the short amplitude condition because their decision was made before movement onset. This result, however, is somewhat inconclusive with regard to our original question. We could not find evidence to support the idea that not replicating the Garner interference in manual estimation was due to differences of setup (distance/decision amplitude) between our study and Ganel and Goodale (2003). Notably, Garner interference in RTs of the manual estimation tasks were remarkably consistent across Experiments 1–4 and had a size of about 6 ms (albeit not consistently significantly different from 0).

Is Response Variability a Better Measure for Garner Interference?

In response to Hesse and Schenk's (2013) critique on using RTs, Ganel and Goodale (2014) demonstrated that Garner interference is also present in the variability of the grip aperture during manual estimation but not in grasping. This variability-based Garner interference is assumed by Ganel and Goodale (2014) to be more robust than simple RT to show differences between the baseline and filtering conditions.

In our experiments, we also tested for variability-based Garner interference in manual estimation and grasping. The results suggest that, while RT effects of Garner interference seem to be unreliable, variability effects seem to be small, but rather consistently observable in both grasping and manual estimation. In Experiment 1, both types of grasping and manual estimation had a similar Garner interference in the variability, with manual estimation showing the smallest effect. In Experiments 2 and 3, we found a numerically consistent and statistically significant Garner interference effect in the variability for manual estimation. In Experiment 4, we found a small and statistically nonsignificant variability-based Garner interference in open-loop manual estimation.

Since variability-based Garner interference was identified and presented as a relevant dependent variable of interest only later, in Ganel and Goodale (2014), many of the other studies on Garner interference did not adopt this analysis. For our literature review, we obtained data of the other studies and present the values of variability-based Garner interference for the first time. These results (see Table 9 and Figure 8) revealed that variability-based Garner interference was largest in open-loop grasping—which cannot easily be accommodated by the PAM.

To summarize, while RT results for a perception–action dissociation regarding Garner interference are somewhat inconclusive because there seems to be no clear Garner interference effect in manual estimation, variability-based Garner interference shows consistent effects in manual estimation. However, we obtained similar effects in grasping in Experiment 1 and through our literature review (see Tables 2 and 9). This discrepancy is even more prominent in open-loop conditions because the largest effects were obtained where none were expected (grasping) and vice versa (manual estimation, see Figure 8). Future research should investigate this difference between open-loop and closed-loop conditions and whether this variable can be established as providing strong support for the PAM.

Is Garner Interference Present in Ventrally Processed Unusual Grasping?

We have so far focused on right-handed precision grasping, as this is assumed the prototypical task for which the dorsal stream is responsible (Gonzalez et al., 2008). Yet, besides the central claim of the PAM regarding Garner interference in manual estimation, but not grasping, there are further predictions that are not supported by empirical evidence. Briefly, they concern situations that use some sort of grasping but in rather unusual conditions like grasping 2D objects (as opposed to 3D), grasping with a tool, grasping with the left (or nondominant) hand, or in an awkward manner not involving the thumb and index finger but rather the thumb and ring finger. Under these conditions, it is assumed by the PAM that "the grasp is more deliberate and less practiced" and that "cognitive supervision of the grasp would recruit ventral stream processing" (Gonzalez et al., 2008, p. 629). Consequently, it is expected that the representations underlying these unusual grasping conditions are more holistic than analytical. Hence, Garner interference should be observable in these tasks. In the following, we will summarize relevant results for grasping 2D objects (Freud & Ganel, 2015) as well as left handed, awkward, and tool grasping (Eloka et al., 2015; Janczyk et al., 2010).

Grasping 2D Objects

Freud and Ganel (2015) investigated grasping 2D objects and found variability-based Garner interference (0.99 $\pm$ 0.25 mm), but the Garner interference in RTs did not reach significance (12 $\pm$ 9 ms). The result for RT in a recent replication by Löhr-Limpens et al. (2020) in open-loop grasping was similar (-1 ± 5 ms; they used a mirror setup such that participants saw a 2D object, but felt a physical 3D object when they made a grasp toward it), but the variability-based Garner interference (0.41 $\pm$ 0.30 mm) in their single-task condition was much smaller than in Freud and Ganel (2015) and not significant. Freud and Ganel hypothesized that grasping 2D objects may involve interactive dorsal and ventral processing, leading to a lack of Garner interference in RTs. However, the same logic can be used to explain a lack of Garner interference in RTs in 3D grasping (assumed only dorsal processing), especially given that we found similar variability-based Garner interference in grasping (assumed only dorsal processing) and manual estimation (assumed only ventral processing) in Experiment 1. In addition, pointing movements to 2D objects with the computer mouse, a task arguably not very akin to right-handed precision grasping, was not susceptible to Garner interference, while the same stimuli yielded Garner interference in a perceptual task (Janczyk et al., 2013).

Awkward, Left Handed, and Tool Grasping

Gonzalez et al. (2006, 2008) presented evidence that awkward, unskilled grasping (i.e., between thumb and ring finger) and left-handed grasping were sensitive to effects of visual illusions, while right-handed precision grasping was immune to them. This was interpreted as further evidence that certain actions are under ventral control. However, Janczyk et al. (2010) investigated these "ventrally processed actions" using Garner interference. Right-handed participants grasped objects in baseline and filtering conditions with their left hand, with an awkward grasp, and with a tool (pliers) across a series of three experiments. Garner interference was numerically small and not statistically significant in any case (left-handed grasping: 1 $\pm$ 9 ms, awkward grasping: -2 ± 13 ms, tool grasping: 11 $\pm$ 10 ms), even though these supposedly "ventral actions" should involve processing the objects in a holistic manner resulting in Garner interference. In a subsequent study, participants even performed left-handed awkward grasps (i.e., between thumb and ring finger of left hand) and still Garner interference was small (2 $\pm$ 7 ms) and not significant (Eloka et al., 2015).

Overall, these results stand at odds with the predictions of the PAM. The weighted means for "unusual grasping" are depicted by open symbols in Figure 6 and are very similar to "normal grasping." This further shows that the picture of ventral versus dorsal processing for perception versus action with regard to Garner interference is not clear or consistent.

Consequences for the PAM

We have shown that evidence from Garner interference in support of the PAM seems weaker and more inconclusive than previously assumed. As mentioned in the introductory part, Garner interference is only one of the three lines of evidence from healthy participants suggested to show a dissociation between visual processing for perception and action. The other two lines are visual illusions and Weber's law. However, presumed perception–action dissociations for these cases have also not been entirely convincing, and recent studies (Bhatia et al., 2022; Kopiske et al., 2016) have described these problems.

Taken together, the results from behavioral experiments showing perception–action dissociations in healthy humans are mixed and not as clear cut as previously believed. With two out of three lines of evidence unclear, it became increasingly important to examine the third line of evidence based on Garner interference. We observed similar issues and most importantly, empirical inconsistencies. Given this state, all three major lines of evidence in favor of the PAM seem inconclusive currently. Further investigation is required to claim strong support for the PAM from behavioral perception–action dissociations.

Outlook and Conclusions

Generality of Results

The participants in all four experiments were from an international student and employee body of the University of Tübingen. They were all young to middle-aged adults and right handed similar to the participants of Ganel and Goodale (2003, 2014). Because the experimental tasks involved natural and practiced movements performed on a daily basis, we do not expect our results to be specific to the characteristics of our participants. However, previous studies on the topic have focused solely on right-handed participants, partly due to assumptions of the PAM about left-handed movements. Therefore, it is unclear if these results can be generalized beyond right-handed participants. Studies on this topic have used varying stimulus sizes and even length as the relevant dimension instead of width, with similar results (Hesse & Schenk, 2013; Löhr-Limpens et al., 2020). Consequently, we would not expect differences in results from manipulation of these factors. In our experiments, we asked participants to emphasize both speed and accuracy because our measure of interest is RT. Studies only interested in finger apertures might consider emphasizing only accuracy to the participants (e.g., Ganel & Goodale, 2014) to reduce the noise in the measurement.

Future Directions

Our investigation into Garner interference and the PAM revealed inconsistencies and open questions. Here, we briefly summarize the issues that should be the basis of future studies to advance this field.

First, not many studies included a manual estimation task. Future research should focus on the critical comparison between grasping and manual estimation in Garner interference experiments rather than taking for granted that manual estimation shows Garner interference. Using a speeded-classification task does not help here because it is more or less resolved and clearly shows Garner interference. Subsequent studies should also use open-loop manual estimation, which only one other study (Schum et al., 2012) and our Experiment 4 employed so far. Open-loop conditions might be more favorable for Garner interference to occur in manual estimation, given the mechanisms suggested by Hesse and Schenk (2013). Also, Haffenden and Goodale (1998) argued that open-loop conditions would be more convincing in grasping because participants could not make any online adjustments based on visual feedback—at least for variables like MGATime and the variability of MGA. Finally, the dependent variables of interest should be clarified. For example, while Ganel and Goodale reported ManEstTime in 2003, they did not report those values for their subsequent higher-powered study in 2014 (we reanalyzed these data and included those results in our Figure 7).

Finally, the question remains whether Garner interference in manual estimation and grasping can be influenced by decision amplitude, as has been shown for speeded classification (Hesse & Schenk, 2013). While we obtained some evidence for RTs being affected by decision amplitude in Experiment 3, we did not see a clear dissociation between long and short conditions in terms of Garner interference. We also did not find a significant Garner interference effect in Experiment 4 where we decreased the response amplitude even further. Answering this open question would also help to resolve whether RTs are suitable to test for Garner interference at all (Hesse & Schenk, 2013).

Conclusion

The idea that Garner interference is present in certain tasks like manual estimation, while visuomotor tasks like grasping do not show Garner interference (Ganel & Goodale, 2003, 2014), is often cited as supportive evidence for the idea of two separate visual streams (PAM; Goodale & Milner, 1992). We showed that this claim lacks empirical support, with only very few studies having investigated manual estimation. In four experiments, we observed that the Garner interference in manual estimation is much smaller than previously reported and more similar to grasping than often assumed. Compiling the results from all available studies on Garner interference in a literature review did not reveal consistent evidence for a dissociation between manual estimation and grasping, and consequently, perception and action.

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(*Appendix follows*)

Appendix

Power Analyses

Here, we describe and calculate the statistical power for Experiments 1–3 from previous studies on Garner interference.

Power for Detecting Garner Interference in Speeded Classification in Experiment 1

Ganel and Goodale (2003) reported in their speeded-classification task shorter RTs for the baseline than for the filtering condition. The mean Garner effect was $M_{SC} = 23$ ms with $t(11) = 2.49$ and $n = 12$ (paired t test). We calculate SEM and SD using:

$$SEM = \frac{M}{t} = \frac{23 \text{ ms}}{2.49} = 9.24 \text{ ms}, \qquad \text{(A1)}$$
$$SD = SEM \times \sqrt{n} = 9.24 \text{ ms} \times \sqrt{12} = 32 \text{ ms}.$$

The effect size Cohen's d_z (for repeated measures) is then:

$$d_z = \frac{M_{\text{diff}}}{SD_{\text{diff}}} = \frac{23 \text{ ms}}{32 \text{ ms}} = 0.72. \qquad \text{(A2)}$$

For our Experiment 1, this results in a power of $1 - \beta = .96$, with $d_z = 0.72$, $n = 24$ and $\alpha = 0.05$ for a one-tailed, paired t test (all power analyses were calculated with the package "pwr" in R).

Power for Detecting Garner Interference in Manual Estimation in Experiments 1 and 2

Similar to above, Ganel and Goodale (2003) reported in their manual estimation task shorter RTs for the baseline than for the filtering condition: Mean difference $M_{ME} = 31$ ms (digitized from their Figure 3), $n = 8$ and $t(7) = 2.39$. This gives $SEM = 13$ ms and $SD = 37$ ms, and further, Cohen's $d_z = 0.84$. Note that this effect was even larger than the effect obtained in speeded classification. This leads one to expect a Garner interference effect in manual estimation that is about as large as the effect in speeded classification, given that they are both ventral tasks and assumed to be processed similarly (holistically).

However, in Ganel and Goodale (2014), the effect size in manual estimation was much smaller: $M_{ME} = 22$ ms, $n = 40$, $SEM = 10$ ms, $SD = 63$ ms, Cohen's $d_z = 0.35$. We therefore list the power values for different effect sizes ranging from 0.84 (Ganel & Goodale, 2003) to 0.35 (Ganel & Goodale, 2014) in Table A1. Note that in Ganel and Goodale (2014) the task was not speeded (Table 4), which is different from Ganel and Goodale (2003). One estimate of the effect size could be the average from the Ganel and Goodale studies, resulting in Cohen's $d_z = 0.60$, for which we have a power of $1 - \beta = .89$ with $n = 24$. For Experiment 2 (where we doubled the number of trials), the power will be even larger.

Power for Detecting Difference Between Manual Estimation and Grasping in Experiment 1

We want to determine the power to detect a larger Garner interference in RTs (filtering – baseline) of manual estimation than in grasping for our repeated-measures design in Experiment 1. Because Ganel and Goodale (2003) used an independent-measures design with different samples of participants for grasping and manual estimation, we need to transform the Cohen's d to a repeated-measures Cohen's d_z (see below).

Table A1
Power Values for Different Cohen's d_z in Manual Estimation in Experiment 1

Cohen's d_z	Value obtained from	Power (one-tailed)
0.35	Manual estimation (Ganel & Goodale, 2014)	0.51
0.40		0.60
0.45		0.69
0.50		0.77
0.55		0.83
0.60	Mean of Ganel and Goodale (2003, 2014)	0.89
0.65		0.93
0.70	≈ Speeded classification (Ganel & Goodale, 2003)	0.95
0.75		0.97
0.80		0.98
0.85	≈ Manual estimation (Ganel & Goodale, 2003)	0.99

For manual estimation, Ganel and Goodale (2003) found a mean Garner effect on RT of $M_{ME} = 31$ ms (digitized from their Figure 3) with $n_{ME} = 8$ and $t(7) = 2.39$. For grasping, Ganel and Goodale (2003) reported only numerical values for "time to complete grasping" but not for RTs (p. 665). Therefore, we used the reported values for "time to complete grasping" as a substitute, $M_G = -3$ ms, $n_G = 12$, $t(11) = 0.3$. Note that this substitute slightly overestimates the SEM (due to more noise from the movement in "time to complete grasping" than in RT) and therefore slightly *underestimates* the power. As before, we can calculate SEM and SD:

$$SEM_{ME} = \frac{M}{t} = 13 \text{ ms},$$
$$SEM_G = \frac{M}{t} = 10 \text{ ms}, \qquad \text{(A3)}$$
$$SD_{ME} = SEM_{ME} \times \sqrt{n_{ME}} = 37 \text{ ms},$$
$$SD_G = SEM_G \times \sqrt{n_G} = 35 \text{ ms}.$$

Next, we can calculate the pooled SD (pSD) for grasping and manual estimation:

$$pSD = \sqrt{\left(\frac{(n_{ME} - 1) \times SD_{ME}^2 + (n_G - 1) \times SD_G^2}{n_{ME} + n_G - 2}\right)} = 35.5 \text{ ms}. \qquad \text{(A4)}$$

Garner interference in manual estimation RT was $M_{ME} = 31$ ms and in grasping RT it was $M_{G\_RT} = -1$ ms. The effect size Cohen's d (for independent measures and between design) is then:

$$d = \frac{M_{\text{diff}}}{pSD} = \frac{31 \text{ ms} - (-1 \text{ ms})}{35.5 \text{ ms}} = 0.90. \qquad \text{(A5)}$$

We need to convert this d to d_z in order to calculate the power for our repeated-measures design. This conversion can be done using

(*Appendix continues*)

Table A2
Cohen's d_z and Power Values for Different Correlations in Experiment 1

Cohen's *d*	Correlation (*r*)	Cohen's d_z	Power (one-tailed)
0.90	.0	0.64	0.92
0.90	.1	0.67	0.94
0.90	.2	0.71	0.96
0.90	.3	0.76	0.98
0.90	.4	0.82	0.99
0.90	.5	0.90	1.0
0.90	.6	1.01	1.0
0.90	.7	1.17	1.0
0.90	.8	1.43	1.0
0.90	.9	2.02	1.0

Table A3
Cohen's d_z and Power Values for Different Correlations in Experiment 3

Cohen's *d*	Correlation (*r*)	Cohen's d_z	Power (one-tailed)
0.63	.0	0.44	0.79
0.63	.1	0.47	0.83
0.63	.2	0.50	0.86
0.63	.3	0.53	0.90
0.63	.4	0.57	0.94
0.63	.5	0.63	0.97
0.63	.6	0.70	0.99
0.63	.7	0.81	1.0
0.63	.8	0.99	1.0
0.63	.9	1.40	1.0

formula 12 of Morris and DeShon (2002):

$$d_z = \frac{d}{\sqrt{2(1-r)}}. \tag{A6}$$

where r is the correlation between the two measures (this relationship is also stated in Cohen, 2013, p. 46 for the simplest case of $r = 0$).

This leaves us with the task to estimate the correlation. Only one study (Ganel & Goodale, 2014) besides our Experiment 1 investigated grasping and manual estimation in a repeated-measures design. Unfortunately, the values required to calculate the correlation are not reported in that article, and the data are not openly available. Therefore, we calculate possible values of power using $n = 24$, and $\alpha = .05$ for a one-tailed paired t test by varying the value of r from 0 to .9 (Table A2).

Thus, even with a conservative estimate of $r = 0$, we obtain for our Experiment 1 a power of $1 - \beta = .92$ to find a larger Garner interference (i.e., one-tailed test) in the RTs of manual estimation than in grasping. Note, that this high power will still be an underestimate as some correlation is likely (e.g., in our Experiment 1, we found $r = .36$).

Power Analysis for Experiment 3

We want to determine the statistical power to detect a larger Garner interference effect in the short amplitude condition than in the long amplitude condition (for RTs of manual estimation in our repeated-measures design). Such an experiment has not been performed before with manual estimation. Therefore, we needed to estimate the to-be-expected effect sizes from other tasks. For this, we used the results obtained in the speeded-classification task by Hesse and Schenk (2013), for the long condition in their Experiment 1 and for the short condition in their Experiment 2. Note that in Ganel and Goodale (2003) the Garner interference effect size in speeded classification was smaller than in manual estimation ($d_z = 0.72$ vs. $d_z = 0.84$, respectively, cf. Experiment 1). As above, we will first calculate Cohen's d for an independent-measures design, and then convert it to d_z to calculate power for our repeated-measures design.

For the short condition, Hesse and Schenk (2013) reported a mean Garner effect of $M_S = 25$ ms with $n_S = 16$ and $t_S(15) = 2.5$. In the long condition, they found $M_L = 6$ ms (values were given for differences in MT = 6 ms and RT + MT = 12 ms, therefore RT = 6 ms), $n_L = 24$ and $t_L(23) = 1.35$. This gives *SEM*, *SD* and pooled *SD*, using the same formulas as above:

$$\begin{aligned} SEM_S &= \frac{M}{t} = 10 \text{ ms}, \\ SD_S &= SEM_S \times \sqrt{n_S} = 40 \text{ ms}, \\ SEM_L &= \frac{M}{t} = 4 \text{ ms}, \\ SD_L &= SEM_L \times \sqrt{n_L} = 22 \text{ ms}, \\ pSD &= \sqrt{\left(\frac{(n_L - 1)\cdot SD_L^2 + (n_S - 1)\cdot SD_S^2}{n_L + n_S - 2}\right)} = 30.3 \text{ ms}. \end{aligned} \tag{A7}$$

The effect size Cohen's d (for independent-measures design) is then:

$$d = \frac{M}{pSD} = \frac{25\,\text{ms} - 6\,\text{ms}}{30.3\,\text{ms}} = 0.63. \tag{A8}$$

Again, we need to convert this Cohen's d to Cohen's d_z for a repeated-measures design. Therefore, we calculate possible values of power using $n = 32$, and $\alpha = .05$ for a one-tailed paired t test by varying the value of the correlation r from 0 to .9 (Table A3).

Thus, even with a conservative estimate of $r = 0$, we obtain for our Experiment 3 a power of $1 - \beta = .79$ to find a larger Garner interference in the short condition of manual estimation than in the long condition. Note, that this power will still be an underestimate as some correlation is likely (e.g., in our Experiment 3, we found $r = .04$).

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