

Research Report

Dorsal and Ventral Processing Under Dual-Task Conditions

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ABSTRACT—*It is widely acknowledged that visual input is processed along two anatomically and functionally distinct pathways—a ventral pathway for conscious perception and a dorsal pathway for action control. The present study investigated whether the apparent direct and unmediated processing in the dorsal stream is subject to capacity limitations. Specifically, we tested whether a simple dorsal task of grasping an object is affected by the psychological refractory period (PRP), a well-known indication of capacity limitations. Subjects performed an auditory choice reaction task and then, following varying delays, had to judge an object's width (ventral task) or grasp an object across its width (dorsal task). Although these tasks were differentially affected by irrelevant variation of the objects' length, they were subject to comparable dual-task interference. These results show that despite important differences between ventral and dorsal information processing, both modes of processing are constrained by limited capacities.*

According to subjective experience, vision results in a conscious representation of the world that is used to recognize, imagine, or communicate about environmental events. These functions accord with the commonsense understanding of “vision” and can be called vision for perception. Yet another, probably more ancient, function of vision is the control of action, such as grasping or avoiding an object. In this case, visual input is quickly and directly transformed into appropriate motor output. This function has thus been called vision for action (Milner & Goodale, 1995).

Vision for perception and vision for action differ in several respects. First, ventral brain lesions impair object recognition but not object-oriented action (visual agnosia), whereas dorsal lesions impair object-oriented action but not object recognition

(visual ataxia). This suggests that the neural substrates for conscious perception and unconscious action control are distinct (see Goodale, Westwood, & Milner, 2004, for a recent review). Second, task-irrelevant context objects or object features affect perceptual judgments but not object-oriented actions. For example, perceptual judgments of an object's width are affected by the object's length, whereas the action of grasping an object across its width is not (Ganel & Goodale, 2003; cf. Aglioti, DeSouza, & Goodale, 1995, for similar observations). Interestingly, irrelevant stimulus features do affect pointing or grasping when these actions are driven by memory instead of direct stimulation (e.g., pointing to a previously seen object that is not currently visible; e.g., Bridgeman, Peery, & Anand, 1997). Thus, vision for action typically relies on directly available, rather than memorized, input. To summarize, there are several functional differences between processing input for perception and processing input for object-oriented action, and a dual-pathway model can elegantly account for these differences.

In the present report, we scrutinize an assumption about another, often implied, feature of the vision-for-action system. Given that vision for action can operate independently of awareness, memory, and interference from irrelevant stimulation, it is generally assumed to work automatically (e.g., Jeannerod & Jacob, 2005, p. 307), and to not be affected by capacity limitations. At first glance, this makes sense. A typical dorsal task, such as picking up an object, appears to be effortless, is practiced over and over, and is unaffected by concurrent tasks, such as talking to another person who is nearby. Moreover, performing a task without awareness is often considered a hallmark of automaticity (Fitts & Posner, 1967; Hasher & Zacks, 1979). Yet, on reflection, one may well argue that even such an apparently effortless task involves several processing steps, such as selecting the to-be-grasped object (i.e., some type of selection for action; Allport, 1990) and computing its viewer-related location. To the best of our knowledge, it has never been tested explicitly whether processing of visual input in dorsal streams is constrained by limited capacities, and if so, whether these limited capacities are confined to the dorsal system, or shared for performance of other, nonvisual tasks as well.

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The purpose of the present study was to begin to answer these questions.

We employed a classical dual-task situation, the psychological refractory period (PRP) paradigm, in which capacity limitations become easily apparent (Welford, 1952). Subjects have to respond to two stimuli presented in close temporal proximity. Typically, reaction times (RTs) to the second stimulus increase as the stimulus-onset asynchrony (SOA) decreases (the PRP effect proper). The PRP effect suggests that a certain capacity has to be divided when tasks overlap in time. Often the first task absorbs all the capacity available, so the tasks have to be performed serially. Although the nature of the capacity in question is not entirely settled, it seems to be involved in many cognitive processes, such as response selection, memory encoding, and certain perceptual operations (e.g., Jolicoeur & Dell'Acqua, 1998; Pashler, 1994).

In our study, subjects first performed a choice reaction task (CRT) in which they responded to the pitch of a tone. We selected an auditory stimulus for this task so that it would be unlikely to involve specific resources confined to visual perception. The second task began after a variable delay. A visual object was presented, and the task was either to judge the object's width or to grasp the object across its width (see Fig. 1). We modeled these tasks after those used by Ganel and Goodale (2003), who demonstrated that they bear differentially on ventral processing (judgment) and dorsal processing (grasping). The ventral task was included to allow a direct comparison of its processing limitations with those of the grasping task (if such limitations occur at all). Note that unlike other "simple" tasks, which show a PRP effect (e.g., braking one's own car when a leading car slows down—Levy, Pashler, & Boer, 2006; tasks with a highly compatible stimulus-response mapping—Brebner, 1977), grasping is directly oriented to and thus guided by the stimulus itself. It is hard to judge from available evidence whether such an object-oriented task would produce a PRP effect as well.

To be sure that the dual-task context did not alter the way the tasks are carried out, we included a control variable that would indicate the involvement of dorsal as opposed to ventral processing. We compared two types of conditions. In *baseline blocks*, the objects varied exclusively according to their width, whereas in *filter blocks*, they varied according to their length as well. Variation of an irrelevant stimulus feature (in this case, length) is known to delay perceptual judgments (Garner interference; Garner, 1974), but not grasping (Ganel & Goodale, 2003). We expected to replicate this dissociation, which would confirm that we were actually tapping into ventral versus dorsal processing. The crucial question was whether a concurrent capacity-limited CRT differentially affects tasks that show this dissociation. Specifically, we were interested to see whether any capacity limits in the grasping task would become apparent. A secondary goal was to determine whether Garner interference is additive or underadditive to the effects of SOA. According to standard PRP logic, an additive effect would allow us to infer that Garner

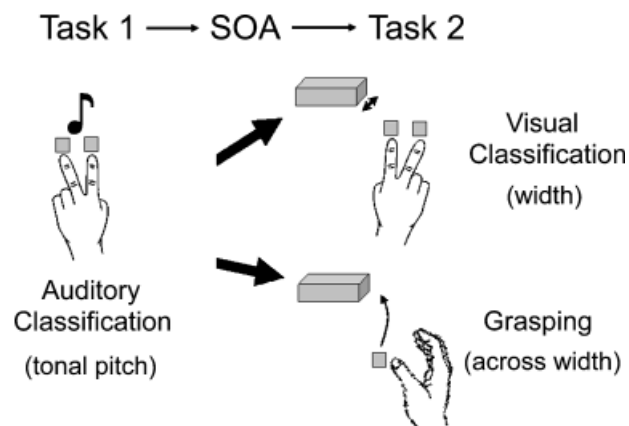


Fig. 1. Illustration of the tasks used. Task 1 was an auditory choice reaction task. Task 2 required speeded perceptual judgment of an object's width or grasping of the object across its width. SOA = stimulus-onset asynchrony.

interference is resolved at a capacity-limited stage of processing, whereas an underadditive interaction would indicate that it is resolved before the capacity-limited stage of processing (see Pashler, 1994, and the Discussion section).

METHOD

The subjects were 24 students (4 male; mean age = 21.25 years) from the Martin-Luther-University of Halle-Wittenberg, Germany.

During the experiment, subjects sat in a dimly lit room in front of a table. In Task 1, they were required to indicate the pitch (300 or 900 Hz) of a 50-ms tone emitted by the loudspeaker of an IBM-compatible computer. Responses were made by using the index and middle fingers of the left hand to press the keys of an immobilized computer mouse. Both versions of Task 2, the ventral and the dorsal version, were modeled after the tasks in the study by Ganel and Goodale (2003). The Task 2 stimuli were four wooden blocks (15 mm thick) that were created from a factorial combination of two different widths (30 mm and 35.7 mm) and two different lengths (75 mm and 63 mm). In each trial, one of these blocks was placed on a rack (100 mm × 100 mm × 15 mm). The rack rested on four mechanical springs; removal of the block caused the springs to lift the rack by 2 mm, thereby opening a microswitch. For the ventral task, subjects placed the index and middle finger of the right hand on custom-made response buttons. Half the subjects were told to press the left button when the object was wide and the right button when it was narrow. For the other half of the subjects, this mapping was reversed. For the dorsal task, subjects placed the right index finger on a home key (30 cm in front of the object) and were asked to grasp the object across its width, using a precision grip, as quickly as possible when the shutter glasses opened. RT was the interval from stimulus presentation to release of the home key. Movement time (MT) was the interval from releasing the home key to lifting the object.

Subjects wore computer-controlled shutter glasses (ASUS VR-100, Asutek Computer Inc. International, Taipei, Taiwan) that controlled the presentation of the Task 2 stimuli. Each trial started with a 40-ms warning click. Then the Task 1 tone was presented. Following a randomly determined SOA of 50, 500, or 1,000 ms, the shutter glasses opened, and the Task 2 stimulus became visible. To avoid response grouping, we instructed subjects to respond to the tone as quickly as possible (Ruthruff, Pashler, & Hazeltine, 2003). After both tasks were completed, the experimenter gave accuracy feedback. In the grasping task, a trial was counted as an error trial if the object was not grasped in the correct manner (e.g., if a precision grip was not used). After the feedback, the glasses turned opaque, the subject was asked to prepare for the next trial, and the experimenter placed the object for the next trial on the rack. When the subject indicated he or she was prepared, the experimenter pressed the space bar of the computer, and the warning click for the next trial was emitted 1,000 ms later.

Participants performed two different tasks as Task 2, perceptual judgment and grasping. These tasks were presented in blocked conditions and in two types of blocks, baseline and filter. In baseline blocks, only the two short objects or only the two long objects were used, and subjects were told beforehand that the objects would differ only in width. Each of the two baseline blocks (one block for each object length) for each Task 2 contained 72 trials (2 pitches in Task 1 \times 3 SOAs \times 2 object widths \times 6 repetitions). In filter blocks (one for each Task 2), all four objects were used. For each task, the number of trials in the two kinds of blocks was equated by including 144 trials in the filter block. The order of trials within blocks was random. The order of filter and baseline blocks and the order of the dorsal and ventral tasks (i.e., which Task 2 was presented first) were counterbalanced across subjects.

RESULTS

The data were screened for outliers according to the nonrecursive procedure of van Selst and Jolicoeur (1994; cf. Thompson, in press), and only outlier-free trials were included in subsequent analyses. The screening procedure was applied separately to RTs in the first task and RTs in the second task (RT1 and RT2, respectively), resulting in removal of 4.7% of the raw data.

Task 2

RTs

Error-free trials were submitted to an analysis of variance (ANOVA) with repeated measures on the factors type of Task 2 (judgment vs. grasping), SOA (50 vs. 500 vs. 1,000 ms), and condition (baseline vs. filtering). The means for this analysis are shown in Figure 2. RT2 increased with decreasing SOA, indicating a PRP effect, $F(2, 46) = 457.3$, $p_{\text{rep}} > .99$, $\eta_p^2 = .952$. Expressed as the RT difference between the longest and shortest

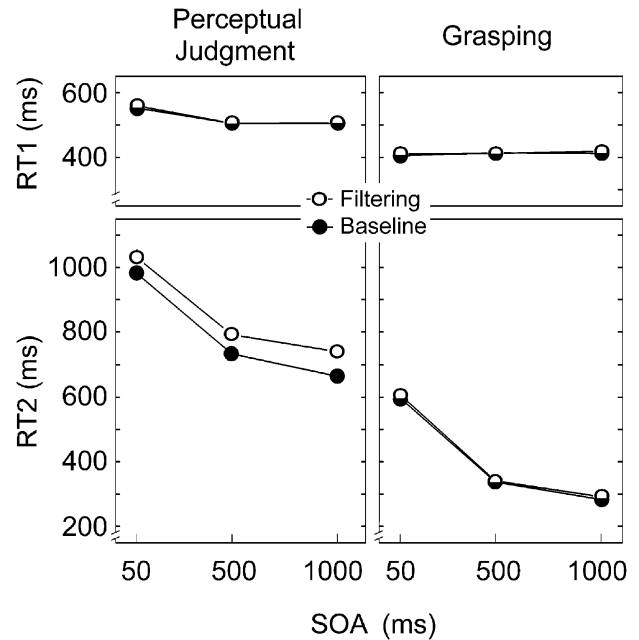


Fig. 2. Reaction times for Task 1 and Task 2 (RT1 and RT2, respectively) as a function of stimulus-onset asynchrony (SOA) and Garner interference condition (baseline vs. filtering). The left panel presents results for trials on which the tone-discrimination task was combined with the perceptual judgment task, and the right panel presents results for trials on which the tone-discrimination task was combined with the grasping task.

SOAs, the PRP effect was almost identical for the judgment task (305 ms) and the grasping task (313 ms), $F < 1$ for the interaction of SOA and task.

Responding was faster in baseline blocks than in filter blocks, $F(1, 23) = 6.80$, $p_{\text{rep}} = .94$, $\eta_p^2 = .228$; thus, there was Garner interference. Yet this was the case only with perceptual judgments, and not with grasping, as indicated by an interaction of task of Task 2 and condition, $F(1, 23) = 4.40$, $p_{\text{rep}} = .88$, $\eta_p^2 = .159$. The 62-ms Garner interference observed in the perceptual judgments was significant, $F(1, 23) = 5.27$, $p_{\text{rep}} = .92$, $\eta_p^2 = .198$, whereas the 7-ms effect found in the grasping task was not, $p > .11$. In the judgment task, Garner interference was additive to the effects of SOA, $p > .24$ for the interaction of SOA and interference.

Finally, RT2 was lower overall for the grasping task than for the perceptual judgment task, $F(1, 23) = 148.6$, $p_{\text{rep}} > .99$, $\eta_p^2 = .866$. No other effects in the RT2 analysis were significant (all $ps > .25$).

MT

In the grasping task, the mean MT was 441 ms. ANOVA revealed no reliable effects on MT (all $ps > .14$).

Error Rates

The error rates were higher for perceptual judgments ($M = 10.6\%$) than for grasping ($M = 2.1\%$), $F(1, 23) = 105.8$, $p_{\text{rep}} > .99$,

$\eta_p^2 = .821$. Whereas error rates tended to increase slightly (by 0.5%) as SOA increased in the grasping task, they tended to decrease (by 1.7%) as SOA increased in the judgment task. Thus, SOA and type of Task 2 interacted, $F(1, 23) = 8.19, p_{\text{rep}} > .99, \eta_p^2 = .263$. No other effect reached significance.

Task 1

RTs

Responding in Task 1 was faster overall when this task was combined with grasping instead of perceptual judgment, $F(1, 23) = 60.9, p_{\text{rep}} > .99, \eta_p^2 = .726$. RT1 increased with decreasing SOA, $F(2, 46) = 15.27, p_{\text{rep}} > .99, \eta_p^2 = .399$, but this was the case only when Task 2 was the perceptual judgment task, not when the second task was grasping, $F(2, 46) = 23.59, p_{\text{rep}} > .99, \eta_p^2 = .506$, for the interaction of SOA and type of Task 2. No other effect approached significance (all F s < 1).

Error Rates

The mean error rate was low (1.2%), and the fact that there were no errors in many conditions ruled out a reasonable statistical analysis. Yet no speed-accuracy trade-offs were apparent.

DISCUSSION

The present study yielded several important results. First, judging an object's width, but not grasping an object across its width, was affected by irrelevant variations of the object's length. This dissociation confirms that the same object is processed along functionally dissociable neural pathways depending on task demands (Ganel & Goodale, 2003). Second, a speeded perceptual judgment (i.e., a typical ventral task) was considerably slowed by a concurrent auditory CRT. Hence, ventral processing is constrained by limited capacity. Third, and most important, grasping an object was subject to massive dual-task interference as well. This result does not accord with the assumption that processing along the dorsal path can be construed as automatic (e.g., Goodale & Milner, 2004, p. 47; Jeannerod & Jacob, 2005, p. 307). Thus, even though processing in the dorsal stream appears to be fast, effortless, and unconscious, it is capacity limited.

Interestingly, grasping and perceptual judgment interfered with the primary auditory task to a similar extent when interference was measured as the overall PRP effect (cf. Fig. 2). Moreover, grasping and the auditory task involved different perceptual modalities (visual vs. auditory) and different forms of motor execution (starting to grasp vs. button pressing). It is therefore tempting to conclude that the observed interference effects occurred at a "central" level, rather than at a perceptual or motor-execution stage. However, the dorsal and ventral tasks differed as well, so it is possible that similar dual-task effects resulted from interference at different processing stages, which coincidentally delayed responding to a similar extent. Thus, the locus of inter-

ference, particularly in the dorsal task, should be investigated further. Still, the results demonstrate that there is a bottleneck in dorsal processing, be it identical with the bottleneck in ventral processing or not. If there were no bottleneck in dorsal processing, grasping RTs should have been independent of the temporal overlap with another task, which was not the case.

It is also noteworthy that Garner interference in the judgment task was additive to the effects of SOA (see Fig. 2). This additive effect indicates that Garner interference is resolved at a central level of processing (cf. Pashler, 1994). This conclusion might seem counterintuitive, as Garner interference appears to be a perceptual phenomenon, comparable to visual masking or degradation, which typically produce underadditive interactions with SOA (e.g., Paelecke & Kunde, in press). Yet there is independent evidence suggesting that a number of task-specific perceptual operations rely on central machinery (reviewed in Pashler & Johnston, 1998, p. 172). Resolving Garner interference is among these capacity-limited perceptual operations (see also Lachmann & van Leeuwen, in press).

Finally, type of Task 2 had a small effect on RT1, which was generally higher and more dependent on SOA when the second task involved perceptual judgment rather than grasping (see Fig. 2). These effects accord with a recent capacity-sharing model holding that processing capacity is shared in a graded fashion between tasks, rather than devoted to tasks serially (Tomblu & Jolicoeur, 2005). The fact that RT1 increased with decreasing SOA in the perceptual judgment task and not the grasping task suggests that the perceptual judgment absorbed more capacity than grasping. Given that RT1 was higher with judgment than with grasping even at the longest SOA, some capacity was reserved for perceptual judgment even before the first stimulus appeared. This inference surely needs further support. At any rate, this aspect of the data does not contradict our main conclusion that dorsal processing is capacity limited.

To conclude, the present study merged two lines of research, research on the two-visual-systems model and research on dual-task interference. This combination revealed that although vision for perception and vision for action differ in how an object is processed, they do not differ as regards capacity limitations. Specifically, object-oriented action might be free from consciousness and subjective effort, but it is not free from capacity limits.

Acknowledgments—We thank Hal Pashler and an anonymous reviewer for helpful comments. This work was funded by the German Research Foundation (DFG).

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(RECEIVED 2/24/06; REVISION ACCEPTED 5/15/06;
FINAL MATERIALS RECEIVED 5/30/06)