

# Attention for perception and action: task interference for action planning, but not for online control

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**Abstract** Human vision allows us both to perceive our surroundings (e.g., identify a cup) and to interact with them (e.g., reach for a cup). It is generally accepted that these functions are supported by a ventral system for conscious object identification and a dorsal system for unconscious control of action, but little research has addressed the extent to which these two systems can operate concurrently. We show that the identification of one object interferes with the planning of a pointing action to a second object, but does not interfere with the visually guided control required to complete the action. This lack of interference holds even for actions that must be modified in response to a dynamically changing scene. These findings support the proposal that the planning of action shares resources with conscious tasks of perception, but that the online control of already-initiated actions does not.

**Keywords** Attention · Visual perception · Psychomotor performance

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## Introduction

A large body of research supports the idea that human vision consists of at least two different cortical systems: a ventral stream for conscious perception of objects (e.g., identification, categorization) and a dorsal stream for unconscious, online control of visually guided action toward objects (e.g., pointing, grasping; Milner and Goodale 1995; but see also Franz et al. 2000; Glover 2004). Here, we use this dual systems theory as a novel framework for examining dual-task performance by studying how the ventral and dorsal systems interact when they are required simultaneously.

A typical way to study the human ability to share mental resources among tasks is the dual-task paradigm, in which participants are asked to perform two tasks at once or in close succession to one another. A comparison of performance under dual- and single-task conditions is used to index the efficiency with which participants are able to perform tasks concurrently. Extensive research of this kind indicates that it is generally difficult to perform two visual tasks concurrently, with performance deficits exhibited in the task that is given lower priority by the participant or that is presented second in time (see Pashler 1998; Shapiro 2001 for reviews).

The dual systems theory of Milner and Goodale (1995) raises the possibility that some forms of efficient multi-tasking may be possible if the appropriate tasks are combined. For example, some researchers have speculated that if one task relies primarily on the ventral stream and another relies on the dorsal stream, then efficient task sharing may be possible (Liu et al. 2003; Norman 2002). Unfortunately, in existing dual-task studies combining action and perception, this hypothesis has not been specifically tested with any rigor, largely because the paired

tasks did not place selective demands on the two streams of processing. For example, some studies required participants to point to one colored shape while simultaneously trying to identify a letter in a separate location (Deubel et al. 1998). Other studies required participants to grasp a target object while simultaneously monitoring for changes in the luminance of a second object (Castiello 1996). Since pointing and grasping are thought to be under dorsal-stream control and object identification under ventral-stream control, these could be construed as existing tests of the hypothesis. And since significant task interference was observed in both studies, one might conclude that efficient multi-tasking is not possible between the visual streams. Indeed, the visual attention model argues for a unitary, object-centered view of attention (Schneider 1995) and predicts that if attention is focused on one target for perception, it cannot simultaneously focus on a second target to complete an action.

However, we do not consider the existing data to be strong tests of the hypothesis for efficient ventral- and dorsal-stream task sharing. This is mainly because, in both cases discussed, to carry out the limb action, the color or shape of an item must be registered (ventral stream function) before the appropriate action (dorsal stream function) is initiated. A more appropriate pointing task, for example, might entail the correction of an already-initiated pointing movement in response to the undetected displacement of luminance-defined visual target (Chua and Enns 2004; Fecteau et al. 2001; Pélisson et al. 1986). Because the target displacement is not detected by conscious mechanisms, and yet the appropriate modification is made to the limb trajectory in response to visual input, such a task would be a better candidate for selectively tapping dorsal-stream visually-guided action. This pointing task, in conjunction with a ventral stream letter identification task, is what we used to test the hypothesis of efficient dorsal-ventral task sharing in the present study.

In our experiments, participants monitored a temporal stream of digits for a letter target. They were simultaneously asked to point to a second, peripheral target appearing unpredictably in space and time. Pointing was compared for displaced targets (the peripheral target moved unpredictably to a nearby location upon movement onset) versus stationary targets to ensure that online action control could be distinguished from mere action execution to a remembered target.

We also defined separate behavioral measures for action planning (movement initiation time) and action execution (movement completion time and accuracy). This is important because planning is generally considered to involve processes that occur prior to action initiation, whereas execution consists of processes involved in bringing the action to completion (Henry and Rogers

1960). The duration of the planning phase is typically assessed by measuring the period from target onset to movement onset, and here we will refer to it as movement initiation time (IT). This measure indexes the time needed to complete the mental sub-processes of target identification, response selection, and movement planning or preprogramming. The time between movement onset and completion will be referred to as movement time (MT), because it indexes the time needed for movement execution, including all processes involved in controlling the movement during its execution. In studies measuring the real-time kinematics of limb movement, it can be shown that total MT actually consists of two distinct component phases: (1) an initial, ballistic phase that reflects programming of the movement characteristics (e.g., movement direction, amplitude), and (2) a later phase that reflects refinement and error-correction of the movement, typically incorporating visual feedback in order to minimize the error between the effector and the target (Elliott et al. 2001; Woodworth 1899). This later phase is when online control of action takes place. Online corrections to displaced targets in the present study are therefore expected to result in increases in MT and increases in accuracy.

Measurements of IT and MT were based on the use of a touch screen display in the present study, rather than on the on-line recording of the limb with three-dimensional (3D) motion analysis. This meant that we were able to monitor the total movement planning time (IT), as well as the total movement execution time (MT) and accuracy, but not the subcomponents of movement execution. These fine-grained details of movement execution are not required to answer our primary question, which is whether planning, execution, or both of these components of visually guided pointing to a target object were influenced by dual-task demands of concurrent perception to a separate object.

According to an elaboration of the dual systems theory (Goodale and Milner 2004), action planning and action execution are controlled by the ventral and dorsal streams, respectively. Planning of action is thought to be guided by input from the perceptual system but is nonetheless under conscious control. The relevant brain regions include the ventral stream and right inferior parietal lobule, which allows for the selection of the target object. The execution of action (including its online control), on the other hand, is hypothesized to be controlled by the dorsal stream. The dorsal stream is also thought to control the initial specification of movement parameters (transforming visual information into action coordinates) and can be involved from the time that a response is cued (Westwood and Goodale 2003).

Guided by this framework, we predict that a ventral perception task of letter identification should interfere with movement planning, but not movement execution and

online control to a separate object. This prediction is based on the possibility that there is not a unitary attentional mechanism serving both ventral dorsal streams, but separate mechanisms available to each stream for the control of task performance (Norman 2002).

In Experiment 1, we examined the relations among these measures of action planning and execution using a modified attentional blink procedure (Shapiro et al. 1997). Following the presentation of a central letter for identification, a peripheral pointing target was presented at positive lags of 100, 300 or 700 ms. The attentional blink refers to the typical pattern that results from two-target tasks in which the second of two targets is misidentified when it follows shortly after a first target that is successfully identified. The new question here was whether some aspect(s) of the pointing task would fall prey to the same limitations of attention that typically beset the second target. In Experiment 2, we replicated these aspects of the experiment, but in addition, we included negative lags of 100 and 700 ms, in order to ensure that central-letter identification would be required while the hand was physically in transit to the peripheral target.

## Experiment 1

### Method

#### Participants

Participants were 14 right-handed undergraduate students (eight females, mean age 20.8 years) with normal or corrected-to-normal vision who volunteered in exchange for course credit at the University of British Columbia. Procedures for all studies described were approved by the Behavioural Research Ethics Board of the University of British Columbia.

#### Apparatus and stimuli

Participants were seated without a chinrest at a viewing distance of 57 cm from a 17" Elo Touchsystems screen (sampling frequency 85 Hz) that used iTouch surface acoustic wave technology to register onscreen touches. Movement initiation and completion were determined by the absence or presence of an onscreen touch. Spatial positions were registered as pixel coordinates on the screen at a resolution of  $800 \times 600$ . As each pixel spanned 0.4 mm, this gave the touch screen an effective resolution of 0.4 mm.

The screen was tilt-mounted so that participants' hands could rest on it at waist height. Pointing responses were

made with a stylus held in the right hand. Letter responses were input with the left hand onto a keyboard resting in the lap.

Displays consisted of black items on a light-gray background. The stylus home position was a circle ( $0.6^\circ$  of visual angle) near the screen's left edge. The gaze home position (fixation) was a square ( $0.4^\circ$ ) located  $2.4^\circ$  above the stylus home position. Each trial began with a digit stream ( $0.6^\circ \times 0.5^\circ$ ) at fixation. The digits 0–9 were randomly selected with the constraint that a digit did not repeat until at least two different digits were presented. Digits were presented for 30 ms followed by a 70-ms blank interval. After 5–10 digits had been presented, a single letter was presented (K, N, V, X, Y, or Z), followed by 14 additional digits.

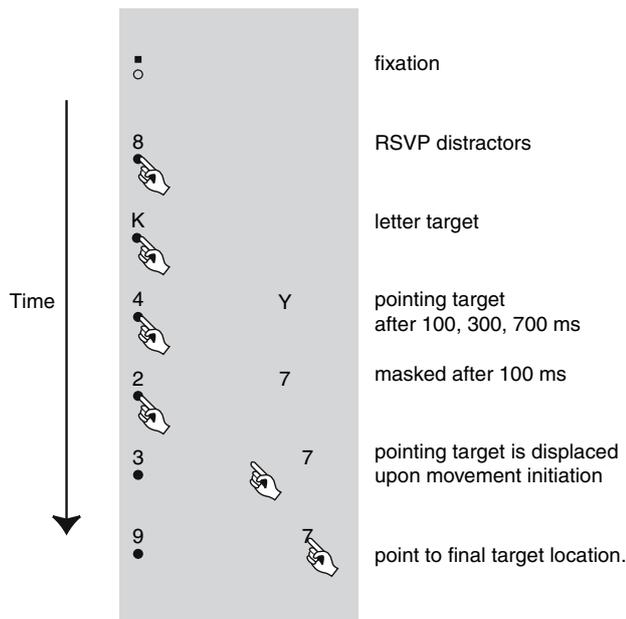
The peripheral letter (pointing target,  $0.6^\circ \times 0.5^\circ$ ) was presented at a Lag of 100, 300, or 700 ms after the central-letter onset. It appeared for 100 ms, followed by a single digit mask that remained visible until pointing completion. Peripheral letters could appear at one of three positions, 110, 120, or 130 mm to the right of fixation ( $10 \text{ mm} = 1^\circ$ ). Peripheral letters were equally divided between a *stationary* (letter and masking digit appeared in a single location) and a *displaced* condition (letter and masking digit appeared at 120-mm location, but upon movement initiation the mask was displaced to a neighboring location).

#### Procedure

A sample trial is shown in Fig. 1. Participants initiated a trial by placing the stylus in the home position, which triggered the central digit stream. Participants were instructed to maintain fixation until the peripheral letter onset, and then to look and point to the peripheral stimulus' final location. Speed and accuracy were stressed. Eye movements were not monitored. Dual- and single-task conditions were tested in separate blocks presented in counterbalanced order across participants. Within each block, trial conditions (temporal lag, target location, target displacement) were randomized. For each of the dual- or single-task conditions, participants performed 20 practice trials followed by 216 experimental trials for that block. In total, participants performed 432 experimental trials each.

In the dual-task condition, participants were instructed to identify the central letter and point to and identify the peripheral target. Accuracy was emphasized for letter identification. Letters were reported after completion of the pointing action. Letter-report order was not constrained; visual feedback indicated letter-report accuracy.

In the single-task condition, participants viewed the same displays, but they were instructed to ignore the central letter and point to and identify the peripheral target.



**Fig. 1** Schematic illustration of a typical trial sequence from Experiment 1 in which the pointing target (peripheral letter followed by digit mask) appears shortly after the letter target appears in the central stream of digits. A displaced target trial is illustrated, in which the peripheral target moves to a new location upon pointing initiation. In Experiment 2, the pointing target was a black disc instead of a letter/digit

### Data analyses

The dependent measures included central and peripheral letter accuracy, and pointing IT, MT, and accuracy. Trials were analyzed if  $100 \text{ ms} < \text{IT} < 2,000 \text{ ms}$  and  $100 \text{ ms} < \text{MT} < 1,000 \text{ ms}$ . Pointing accuracy (and consistency) was assessed with absolute constant error (ICE), absolute value of average horizontal deviation from final target location) and variable error (VE, average standard deviation of horizontal errors from final target location). Vertical pointing accuracy (vertical deviation from final target location) was also analyzed; errors were negligible and there were no effects of any of the analyzed factors, thus, vertical error is not reported. Measures were examined with a repeated-measures ANOVA that included within-participant factors of Task Type (dual, single), Lag (100, 300, 700 ms), and Target Type (stationary, displaced). Significant effects were followed up with simple effects tests and Fisher's LSD protected *t* tests.

To ensure that full attention had been paid to the central letter, peripheral letter accuracy and pointing movements were only analyzed when they followed correct central letter identification. Additionally, when the peripheral target was displaced, the final target location was always the nearest or farthest position, so stationary and displaced targets were compared for these locations.

## Results

The main finding was that central letter identification did not interfere with the speed or the accuracy of pointing to a peripheral letter, even when it was unexpectedly displaced, supporting the independence of perception and the online control of action (Milner and Goodale 1995). At the same time, central letter identification did interfere with the initiation of pointing to the peripheral letter, consistent with the claim that action planning depends on a unitary attention mechanism (Schneider 1995).

### Letter identification

Mean letter identification errors (Fig. 2a) indicated that participants successfully identified the central-letter target, making only 3.5% errors. Central-letter accuracy did not vary with temporal lag between the central and peripheral letter or with Target Type (stationary or displaced), all  $F_s < 1$ .

Identification of the peripheral letter, which was also the pointing target, exhibited a typical attentional blink pattern, namely a Task Type  $\times$  Lag interaction,  $F(2, 26) = 23.31$ ,  $P < 0.0001$ . At short lags, peripheral-letter accuracy was much reduced in the dual-task relative to the single-task condition. However, by lag 700, accuracy in the two conditions was equivalent, indicating that there was no longer any cost associated with correct central-letter identification.

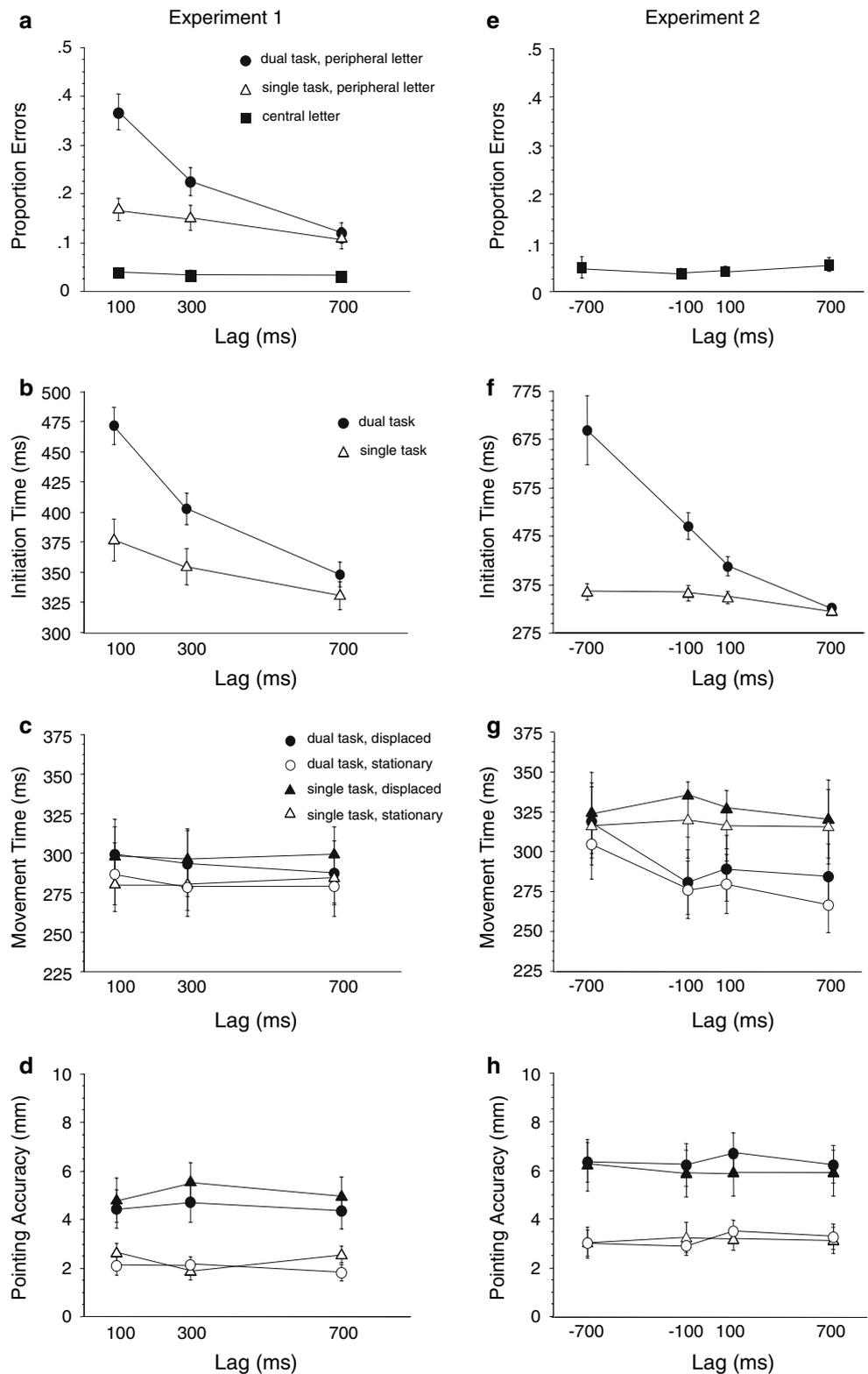
### Initiation time

Mean pointing IT relative to pointing-target onset (Fig. 2b) exhibited the same pattern as peripheral-letter accuracy, namely a Task Type  $\times$  Lag interaction,  $F(2, 26) = 24.64$ ,  $< 0.0001$ . At short lags, dual-task IT was 95 ms longer than single-task IT, but by Lag 700, IT in the two conditions no longer differed significantly.

### Movement time

Mean pointing MT (Fig. 2c) was relatively invariant across Task Type and Lag. Consistent with the need to incorporate the new target location during movement to a displaced target, MT was 14 ms longer when the pointing target was displaced rather than stationary,  $F(1, 13) = 16.22$ ,  $P < 0.002$ . The increase in MT for displaced targets was particularly pronounced for backward jumps; this greater time may have reflected a larger number of acceleration changes for backward jumps (Boulinguez

**Fig. 2** Results in Experiments 1 and 2. Central and peripheral letter identification accuracy (**a**, **e**), pointing initiation time (**b**, **f**), pointing movement time (**c**, **g**), pointing accuracy (absolute constant error) relative to final target location (**d**, **h**). Error bars represent plus/minus one SE



et al. 2001) or a reversal in the direction that the hand was traveling. Importantly, there was no evidence that MT was prolonged in the dual-task relative to the single-task

condition, suggesting that once pointing had been initiated, there was no dual-task interference from central- or peripheral-letter identification on MT.

## Pointing accuracy

Mean ICEI is shown in Fig. 2d. Preliminary analysis of signed constant error indicated that participants overshoot near and undershoot far targets, a typical finding in motor control (e.g., Elliott and Lee 1995). Overall, ICEI was lower for stationary (2.2 mm) than for displaced targets (4.8 mm),  $F(1, 13) = 11.21$ ,  $P < 0.006$ , but neither Task Type, Lag, nor their interaction had any effect on ICEI (all  $P$ s  $> 0.17$ ). Pointing VE supported this conclusion: pointing was more consistent to stationary than displaced targets (by 6 mm),  $F(1, 13) = 21.87$ ,  $P < 0.0005$ . Dual-task pointing was actually more consistent than single-task pointing (by 5 mm),  $F(1, 13) = 8.19$ ,  $P < 0.02$ . Additionally, VE increased with increasing Lag (by 3 mm),  $F(2, 26) = 4.27$ ,  $P < 0.03$ . There was no evidence that accuracy was impaired in the dual-task context, suggesting that once pointing was underway, successful central- or peripheral-letter identification did not impair it.

## Effect of peripheral letter identification

It is possible that the cost in pointing initiation was influenced by the requirement to identify the peripheral letter. However, examination of trials on which the peripheral target was incorrectly identified revealed that pointing IT was slower, not faster, when the peripheral target was incorrectly identified,  $F(1, 11) = 11.5$ ,  $P < 0.007$ . This cost could have been an effect of failing to attend to the tasks in general, or an interference effect from consciously missing the peripheral letter. To further rule out the possibility that correct peripheral letter identification was contributing to the IT cost, a control experiment was conducted for Experiment 1 that shared the same methods with the exception that the peripheral pointing target was a solid disc, rather than a letter ( $n = 14$ , 11 female, mean age 19.9 years). This removed the identification requirement for the second target. When the data from both experiments were analyzed together with Experiment as a between-subjects factor, there was no effect of Experiment on IT (all  $P$ 's  $> 0.36$ ). There was a trend for the control experiment MT to be slower overall (373 ms) than in Experiment 1 (289 ms),  $F(1, 26) = 4.15$ ,  $P < 0.06$ . Comparison of ICEI to that in Experiment 1 revealed that errors were generally lower in the control experiment,  $F(1, 26) = 4.25$ ,  $P < 0.05$ . With regards to the effect of prolonged MT and reduced errors, there may simply have been a speed-accuracy tradeoff, such that longer MT resulted in lower errors for those movements. Importantly, there were still no dual- versus single-task costs in movement time or error.

## Experiment 2

### Method

Participants were 14 right-handed students (11 females, mean age 19.9 years) with normal or corrected-to-normal vision who volunteered in exchange for course credit at the University of British Columbia. These participants had not taken part in the previous experiment but were recruited in the same manner. The method was identical to Experiment 1 with the following exceptions. The pointing target was a  $0.5^\circ$  black disc that did not have to be reported. The disc could appear 700 or 100 ms before or 100 or 700 ms after the central letter. Two-hundred and forty trials were tested in each of the dual- and single-task conditions. Since the central-letter target now appeared unpredictably before or after the pointing target, participants were instructed to maintain fixation on the central stream throughout the trial. Eye movement monitoring was unnecessary because the central letter task could not be completed outside of central gaze. The pointing target was fully visible in the periphery and the results showed that online control was successful under these conditions, consistent with previous reports (Diedrichsen et al. 2004).

### Results

The main finding was that even when the hand was in flight, letter identification did not interfere with online control of pointing.

#### *Letter identification*

Mean letter identification errors (Fig. 2e) were again very low (4.6%) and did not vary with Lag or Target Type, all  $F$ s  $< 1$ .

#### *Initiation time*

Mean pointing IT (Fig. 2f) was similar to Experiment 1 in showing a Task Type  $\times$  Lag interaction,  $F(3, 39) = 29.03$ ,  $P < 0.0001$ . Dual-task IT was elevated by over 330 ms from single-task IT at Lag  $-700$ ; this interference effect gradually diminished until it was absent at Lag 700.

#### *Movement time*

Mean pointing MT (Fig. 2g) showed a Task Type  $\times$  Lag interaction,  $F(3, 39) = 7.25$ ,  $P < 0.001$ , but it favored MT in

the dual-task conditions. That is, MT was faster in the dual-task than the single-task condition at every lag except for  $-700$  ms ( $P_s < 0.0001$ ), suggesting that dual-task requirements resulted in an MT improvement. Also, as observed in Experiment 1, MT was longer (by 11 ms) for displaced than for stationary targets,  $F(1, 13) = 5.38$ ,  $P < 0.04$ .

### Pointing accuracy

Mean pointing |CEI| (Fig. 2h) was similar to Experiment 1. |CEI| was lower for stationary (3.2 mm) than for displaced targets (6.2 mm),  $F(1, 13) = 17.63$ ,  $P < 0.002$ , but neither Task Type, Lag, nor their interaction had any effect on |CEI| (all  $P_s > 0.44$ ). VE analyses supported the same conclusion: pointing was less consistent to displaced than to stationary targets,  $F(1, 13) = 16.12$ ,  $P < 0.002$ , but no other factors were significant (all  $P_s > 0.24$ ).

### Pointing initiation relative to letter onset

The preceding analyses were premised on the assumption that pointing in the  $-700$  Lag condition actually began prior to central-letter onset. However, actual initiation time varied across trials and participants, so those analyses may have masked interference effects that only occurred if the central target appeared after pointing had begun. To examine this possibility, trials were sorted into four bins according to when the pointing action was actually initiated, as shown in Table 1. Bin 1 ( $-600$  to  $-200$  ms, 896 trials) only included movements that were initiated well before letter onset, Bin 2 ( $-200$  to  $+200$  ms, 472 trials) included movements beginning near or during letter onset, Bin 3 ( $+200$  to  $+600$  ms, 2,281 trials) included movements beginning shortly after letter onset, and Bin 4 ( $+600$  to  $+2,000$  ms, 1,382 trials) included movements beginning long after letter onset.

These analyses were completely consistent with those already presented. There were no significant effects on MT, accuracy, or VE showing interference from letter identification as a function of Task Type or Bin (all  $P_s > 0.10$ , Table 1). Online control was still evident, as participants were modifying pointing to displaced targets regardless of lag. As in the preceding analyses, dual-task MT was faster than single-task MT at later bins,  $F(3, 27) = 4.37$ ,  $P < 0.02$ , and accuracy and VE were worse for displaced than stationary targets (accuracy:  $F(1, 9) = 20.11$ ,  $P < 0.002$ ; VE:  $F(1, 9) = 6.08$ ,  $P < 0.04$ ). The important finding was that with the current behavioral measures, no interference was observed in the online control of pointing, regardless of when it occurred relative to the attention-demanding task of central-letter identification.

**Table 1** Mean movement time (in ms) and pointing accuracy (in mm) as a function of pointing initiation time relative to central letter onset in Experiment 2

		Bin			
		1	2	3	4
Movement time (ms)					
Single task stationary	M	307	286	298	301
	SE	47	37	41	43
Single task displaced	M	304	304	315	301
	SE	46	43	48	45
Dual task stationary	M	303	313	261	252
	SE	55	41	34	30
Dual task displaced	M	308	299	268	262
	SE	54	50	37	33
Accuracy (absolute constant error, mm)					
Single task stationary	M	2.81	4.09	3.19	3.07
	SE	0.57	0.90	0.40	0.46
Single task displaced	M	7.27	6.28	6.49	6.62
	SE	1.53	1.20	1.22	1.14
Dual task stationary	M	3.29	3.28	3.12	3.23
	SE	0.57	1.00	0.44	0.45
Dual task displaced	M	7.26	6.81	7.11	6.62
	SE	0.97	1.31	1.02	0.94

Bin 1 includes all movements initiated  $-600$  to  $-200$  ms before letter onset, Bin 2 includes movements initiated at  $-200$  to  $200$  ms, Bin 3 includes  $200$  to  $600$  ms, and Bin 4 includes  $600$  to  $2000$  ms

M Mean, SE standard error of mean

### General discussion

Experiment 1 demonstrated that successful letter identification interferes with identifying a second letter in a peripheral location (Shapiro et al. 1997) and with initiation of pointing to this peripheral letter. However, no interference was evident in either the speed or accuracy of the ensuing pointing action to the peripheral letter.

Our interpretation is that planning an action shares cognitive resources with letter identification. It is not merely that pointing initiation has been delayed. If there was merely a limit on action initiation during letter identification, with action planning unaffected, then the pointing IT cost should be a direct function of the intervening lag between the onset of the central and peripheral letters. For example, if letter identification took 195 ms before pointing was initiated (the Lag of 100 ms in Fig. 2b plus the dual-task IT cost of 95 ms), then there should no longer be any measurable cost at Lag 300. Yet a cost still exists, suggesting that in addition to any limits on pointing initiation, there is also interference in planning the action concurrently with letter identification. It is also unlikely that the delay in pointing initiation was influenced by requiring peripheral-letter identification. Note that

participants in the Experiment 1 control and in Experiment 2 pointed to a black disc without reporting on its appearance, with the result of dual-task costs for pointing IT but none for pointing MT or accuracy.

Our conclusion that online control can be accomplished without interference during concurrent letter identification is based on the finding that Task Type and Lag had no influence on pointing MT or accuracy, even when the pointing target was displaced upon movement initiation. This means that the system guiding the hand registered the new target location and modified the action accordingly without interference from the letter identification task.

Experiment 2 demonstrated that online pointing control was not impaired by concurrent letter identification even when the letter appeared while the hand was in flight, responding to an unpredictable change in the pointing target location. This experiment also showed that pointing IT was even more delayed for negative than for positive lags. Participants were very reluctant to begin pointing to the peripheral target prior to the onset of the central letter they were trying to identify. Thus, part of the dual-task IT cost for negative lags was likely the result of participants trying to avoid the conflict between action planning and letter identification, because these tasks tap the same resources. Nonetheless, in the critical examination of only the trials where the pointing movement had begun at least 200 ms prior to the central-letter onset, there was still no evidence that letter identification interfered with the online control of pointing. This suggests that only the planning involved in pointing to the initial target location shares resources with letter identification or preparing to identify.

We note that participants' decision regarding the finger's eventual location is not made entirely after hand liftoff. If it were, then accuracy would be comparable for displaced (moving upon hand liftoff) and stationary targets. Instead, accuracy is better for stationary targets, suggesting that planning is complete before movement initiation. However, once the pointing action has been planned, it can be executed and even modified by changes in target location without any interference from letter identification. We also note that letter identification is not being delayed for future completion during the online control of action; the digits following the letter prevented this by acting as backward masks (Brehaut et al. 1999).

An unexpected finding of Experiment 2 was a significant dual-task MT facilitation when the pointing target appeared immediately before or following the letter target (Fig. 2g). This result is surprising given typical dual-task costs. Yet, it concurs with research showing dual-task benefits in visually guided action. For example, researchers have reported benefits in bimanual over manual pointing (Diedrichsen et al. 2004) and in manual peg placement by Parkinson's patients when combined

with a tapping task (Brown and Jahanshahi 1998). The present dual-task MT facilitation concurs with these researchers who remind us that focused attention on an automatic task can interfere with fluent performance (e.g., in sports, performance arts). Attention to a second task can ensure that such overfocusing does not occur, leading to better performance (Arend et al. 2006). This interpretation is supported by our findings that (1) single-task MT did not vary with the time, indicating that nothing in the physical conditions of the task contributed to time-related improvement (Fig. 2g) and (2) the MT benefit occurred specifically when the pointing movement was initiated after the central-letter presentation (Table 1), consistent with an overfocusing interpretation. Any interpretation of a dual-task cost would predict increased, rather than decreased MT, after central-letter processing had begun. The greater consistency of dual-task VE in Experiment 1 may also reflect this dual-task benefit.

These results run counter to the visual attention model (Schneider 1995), which proposes that the visual system can only select a single object at a time, regardless of whether an object is the target of an action or the focus of identification. Yet participants in the present study were clearly able to identify a letter without cost, even while they were able to modify pointing movements to a second object in response to an unpredictable change in its location. This suggests that this model may apply to the planning of action, but not to its online control. The results for online control support the dual-systems theory (Milner and Goodale 1995). Moreover, they are consistent with a proposed modification to the dual-systems theory (Glover 2004) that highlights the need for action planning and online control to be more sharply distinguished. The present results do this by showing the clear dissociability of planning versus control of pointing with regard to an attention-demanding ventral stream task.

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