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Reaction time latencies of eye and hand movements in single- and dual-task conditions

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Abstract. The goal of this study was to investigate whether ocular and hand motor systems operate independently or whether they share processes. Using dual-task methodology, reaction time (RT) latencies of saccadic eye and hand motor responses were measured. In experiment 1, the hand and eye motor systems produced rapid, aimed pointing movements to a visual target, which could occur either to the left or right of a central fixation point. Results showed that RT latencies of the eye response were slower in the dual-task condition than in the single-task condition, whereas the RT latencies of the hand response were virtually the same in both conditions. This interference effect indicated that the ocular and manual motor systems are not operating independently when initiating saccadic eye and goal-directed hand movements. Experiment 2 employed the same experimental paradigm as experiment 1, except for one important modification. Instead of a goal-directed hand movement to the target stimulus, subjects had to make a button-press response with either the index or middle finger of the right hand dependent upon whether the stimulus occurred to the right or left of the control fixation point. The aim of experiment 2 was to investigate the issue whether the observed interference effect in experiment 1 was specific or non-specific (e.g. overhead costs due to coordinating any two responses). The finding that saccadic eye movements and button-press responses in the dual-task condition could be initiated without delay relative to the single-task conditions, supports the specific interference interpretation.

Key words: Eye-hand coordination – Reaction times – Motor control – Dual-task methodology – Human

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Introduction

This paper focuses on temporal coupling between eye and hand movements in the context of pointing to a visual target. In the last decade two relevant questions regarding this issue have been examined: first, whether initiations of eye and hand responses occur in a fixed or variable order (e.g. Abrams et al. 1990; Biguer et al. 1982; Prablanc et al. 1986) and, second, whether eye and hand responses are initiated by one common command signal or by different command signals (e.g. Fischer and Rogal 1986; Frens and Erkelens 1991; Herman et al. 1981; Paillard (1982); Prablanc et al. 1979).

Results of studies addressed to the first question are straightforward. Almost always the eyes start moving toward the target before the hand, and because eye movement durations are quite brief, the eyes usually arrive at the target before the hand starts to move (Abrams et al. 1990).

Answers to the second question, however, are not quite so straightforward. Typically, a correlational approach has been used in order to determine the degree of co-variation between reaction time (RT) of eye and hand movements, high correlations being interpreted as evidence that eye and hand responses are initiated by a common command signal, low correlations as evidence for independent command signals.

Experiments using the correlational method have yielded inconsistent results, widely differing correlations having been reported both within and between studies. For example, low correlations ($r < 0.4$) were reported by Biguer et al. 1982, and by Frens and Erkelens 1991; modest correlations ($0.4 < r < 0.6$) by Gielen et al. 1984, Prablanc et al. 1979, and by Fischer and Rogal 1986; high correlations ($r > 0.6$) were found by Herman et al. 1981 and also in some of the conditions of experiments by Frens and Erkelens 1991 and by Fischer and Rogal 1986. Because most of the studies fail to report high correlations, and because low and modest correlations can easily be attributed to a shared perceptual processing component (Gielen et al. 1984), strong evidence in support of the common command hypothesis is lacking.

Failure to obtain evidence for the common command hypothesis, however, does not automatically constitute evidence in favour of the independent commands hypothesis. Theoretically it is still possible that eye and hand motor systems do work together, but that the degree of cooperation is insufficient to realize strong correlations. To investigate the issue whether eye and hand motor systems operate independently or whether they share processes, *dual-task* methodology[1] was employed in this study. In the single-task condition subjects had to make *either* eye or hand movements to a visual target, while in the dual-task condition *both* hand and eye were required to move to the visual target.

The logic behind dual-task methodology is as follows. When eye and hand movements are executed simultaneously, without an increase in RT latencies in the dual-task condition relative to the single-task conditions, strong support is found for the assumption that both responses are mediated by independent processes. In the case that the RT latencies in the dual-task condition differ from those in the single-task conditions, support is found for the notion that movements produced by eye and hand motor systems share processes.

Experiment 1

Experiment 1 was designed to study RT latencies of eye and hand movements in single- and dual-task conditions. The experimental task required subjects to move (eyes alone, hand alone, or eyes and hand concurrently) as quickly as possible to a large target stimulus appearing either to the left or right of a central fixation point. The choice of a large target size was motivated by the wish to impose low accuracy constraints, i.e. to demand only a ballistic hand response without the need for visually guided error corrections.

Materials and methods

Subjects

Twelve right-hand preferent undergraduate students (three male and nine female, mean age 22 years), participated as non-paid, voluntary subjects. Nine subjects had normal vision, while the three subjects who normally wore glasses were not allowed to wear them during the experiment. As all these subjects had an acuity of at least 18/20 D, the nature of any impairment they experienced was inconsequential for performing visual tasks at short distances as in the present task. All were naive as to the purpose of the experiment.

Design

Each subject served in three conditions on a single day, with each condition lasting 10 min with a break of 5 min between conditions. In the eye-only condition, only the eyes moved to the stimulus; in the hand-only condition, only the hand moved to the stimulus while the eyes remained fixated on the fixation point; in the eye-and-hand condition, both eyes and hand moved to the stimulus. Order of conditions was balanced between subjects.

Apparatus

The experiment was carried out in a normally illuminated room which contained many visual cues. The subject stood behind a horizontally placed transparent X-Y tablet (Scriptel RDT, 105–80 cm). Underneath the X-Y tablet a tv-monitor (Phillips, 54–40 cm) was mounted, controlled by an AT-MSDOS computer. On the monitor a fixation sign was presented in line with the subject's eyes at a distance of about 28 cm. The fixation point was a 'filled dot', diameter 2 deg of arc, and the stimulus was a 'filled rectangle' presented at a distance equivalent to 15.9–24.9 deg of visual angle. Positions of subjects' eyes were monitored with an IRIS system. This system records eye position by reflection of iris-sclera boundaries by means of infrared light; the output of the IRIS system is low-pass filtered (200 Hz, −3 dB); for details see Reulen et al. (1988). The analog output from the IRIS was digitized at a rate of 200 Hz. Calibration was performed at the beginning of each session. The head was fixated by a frame which was connected to the IRIS 35 cm above the middle of the X-Y tablet, so that the eyes were directly above and looking down at the control fixation dot.

The subjects were requested to move a stylus with their right hand over the surface of the X-Y tablet which recorded X-Y coordinates with an accuracy of 0.1 mm at a rate of 172 Hz.

Procedure

A series of 10 practice trials preceded the 20 experimental trials. At the beginning of each trial the subjects were requested to place the stylus on the fixation point. After 2 s, the target stimulus appeared randomly either to the left or to the right of the fixation point. Subjects were instructed to make saccadic eye movements and/or ballistic hand movements towards the target. They were also instructed to minimize both RT and movement time (MT) of eye and/or hand.

Eye-movement analysis

The position data generated by the IRIS system were analysed off line by means of the software program NYSTAGLINER (Toennies, Würzburg) to identify the occurrence of saccades. The beginning of a saccade was defined when the signal exceeded the value of the root mean square (RMS) of the previous 120 ms with a factor 3 within a subsequent window of 20 ms. A trial was excluded from the analysis when another saccade or eye blinking appeared within 100 ms before or after this point of detection. The same criteria were used to check fixation of the eyes in the hand-only condition. Because all subjects showed almost perfect binocular coordination between horizontal saccades (correlation values for each subject >0.99), only data concerning the right eye are presented[2]

Hand-movement analysis

Detection of changes in hand movements (RTs) were calculated by a computer algorithm which included four criteria. The first three

[1] The term dual-task methodology in this paper refers to the *procedure* of studying RT latencies of eye and hand movements in single and dual task conditions. Note that the dual-task *condition* is used in most studies on eye-hand coordination but the single-task condition is not

[2] All trials were visually inspected; in about 10% of the trials of both eye-only and eye-and-hand conditions the automatic detection of a saccade was manually corrected. These manual corrections were invoked when significant eye drifts occurred

samples had to differ at least one unit in x-direction (one unit corresponds to 0.1 mm) from each other, the fourth more than one, the fifth more than two and the sixth sample had to differ more than three units from its preceding x-coordinate.

Correlation analysis.

Within-subject Pearson correlation coefficients were calculated on a trial by trial basis between eye and hand RTs in the dual-task condition. In addition, a between-subject Pearson correlation was calculated using the subjects' mean RTs of eye and hand in the dual-task condition.

Results

The results of one subject were excluded because eye blinks occurred in more than 25% of the trials which required eye movements. For the remaining 11 subjects, 10.0% of trials which required saccadic eye movements in the eye-only condition and 11.8% in the eye-and-hand condition were excluded (see Materials and methods Eye movement analysis).

Table 1 shows mean RT and standard deviation of eye and hand movements in single and dual-task conditions. An ANOVA yielded a significant main effect for task condition (single vs dual), $F_{(1,10)}=12.7$, $p<0.01$, indicating longer reaction times in the dual-task than in the single-task condition (249 and 229 ms, respectively). The main effect of type of movement (eye vs hand) was not significant, $F_{(1,10)}=0.1$, $p>0.2$. Importantly, a significant interaction effect was found between type of movement and task condition, $F_{(1,10)}=19.3$, $p<0.01$. A paired, two-tailed t-test indicated that RT of the eyes was significantly longer (39 ms) in the dual-task condition than in the single-task condition ($T_{(10)}=4.25$, $p<0.002$).

RT latencies of the hand were virtually identical in single and dual-task conditions ($T_{(10)}=-0.23$, $p>0.8$). The RT latencies of the eyes and the hand were not significantly different from each other in the dual-task condition ($T_{(10)}=1.45$, $p>0.15$).[3] None of the individual (within-subjects) correlations between eye and hand RTs was significant, all p values being larger than 0.05. The between-subjects correlation was $r=0.14$, $p>0.05$.

Table 1. Mean RT latencies (ms) and standard deviatons (ms) for eye and hand aiming responses in single- and dual-task conditions (experiment 1)

	Eye	Hand
Single-task	222 ± 35	234 ± 41
Dual-task	261 ± 41	238 ± 42

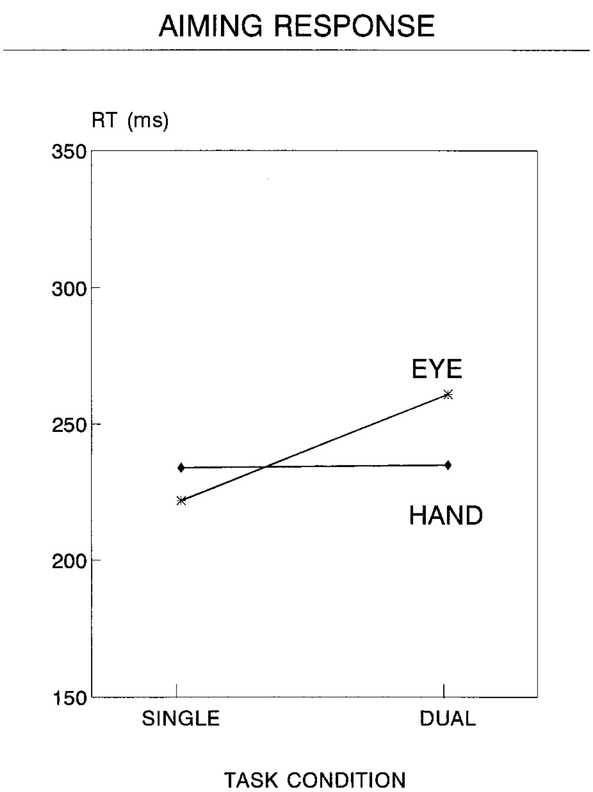

Fig. 1. Mean RT latencies (ms) of eye and hand aiming responses in both single- and dual-task conditions (experiment 1). Saccadic eye RT latencies are longer in the dual-task condition than in the single-task condition

Discussion

The main finding of experiment 1 was that RT latencies of the eyes were consistently and significantly longer in the dual-task condition than in the single-task condition, while those of the hand did not differ significantly. In addition, no significant correlations were found. Non-significant or low correlations do not support the common command hypothesis but, as stated in the Introduction, low correlations do not constitute strong evidence for the notion that the eye and hand motor systems operate independently. In fact, the interference effect for the eye response in the dual-task condition indicates that the ocular and manual motor systems do not operate independently; rather, at some stage, processes seem to be shared.

The question to which this finding gives rise is whether or not the observed interference effect is specific or non-specific i.e. the consequence of being required to produce *any* two responses, or the sharing of specific processes in the context of pointing to a target.

One way to discriminate between these two interpretations is to manipulate the nature of the manual response. This is done in experiment 2.

Experiment 2

The same paradigm as for experiment 1 was used except for one important modification. Instead of a goal-directed hand movement to the target stimulus, subjects had to make a button-press response with either the index or

[3] The mean difference between RT latencies of eye and hand in dual-task condition was 23 ms. However, the large variation in eye and hand RTs (SD 54) makes this difference non-significant

middle finger of the right hand. Specifically, the left target stimulus required a button-press response with the index finger and the right target stimulus a button-press response with the middle finger. The same saccadic eye movement was required as in experiment 1.

The purpose of this manipulation is straightforward. If experiment 2 shows the same interference effect as found in experiment 1, support is provided for non-specific interference. On the other hand, if the interference effect disappears, support is found for a specific interference effect caused by a sharing of processes associated with the control of coordinated aimed eye and hand movements.

Materials and methods

Subjects

Twelve right-hand preferent undergraduate (five male and seven female) students (mean age 23 years) participated as non-paid, voluntary subjects. All had normal vision, and all were naive as to the purpose of the experiment. None of them had taken part in the previous experiment.

Procedure

Instead of making a goal-directed hand movement, subjects were requested to press one of two buttons on a response box with either the index finger, when the stimulus was presented to the left of the fixation sign, or with the middle finger when the stimulus was to the right. The subjects were required to keep the two fingers on the buttons during the experiment.

The design, apparatus and eye-movement analysis were the same as in experiment 1.

Finger-movement analysis

A connection was made between the response box and the AT-MS-DOS computer by means of the joystick port. This port scanned both button states (high or low value) at a rate of 1000 Hz. The values were analysed off-line. A trial was excluded when no response occurred within a period of 750 ms or when a subject pressed the wrong button.

Results

We excluded 3.1% of trials requiring saccadic eye movements in both the eye-only and the eye-and-finger condition, 0.7% of trials requiring finger responses in the finger-only and 1.7% of trials in the eye-and-finger condition.

Figure 2 shows the mean RT latencies of eye and finger responses in single- and dual-task conditions. A main effect was found for type of movement, indicating that the RT latencies of the eyes (217 ms) were significantly shorter than the RT latencies of the finger (316 ms), ($F_{(1,11)}=44.5$, $p<0.001$). No main effect was found for task condition, ($F_{(1,11)}=3.2$, $p>0.05$).

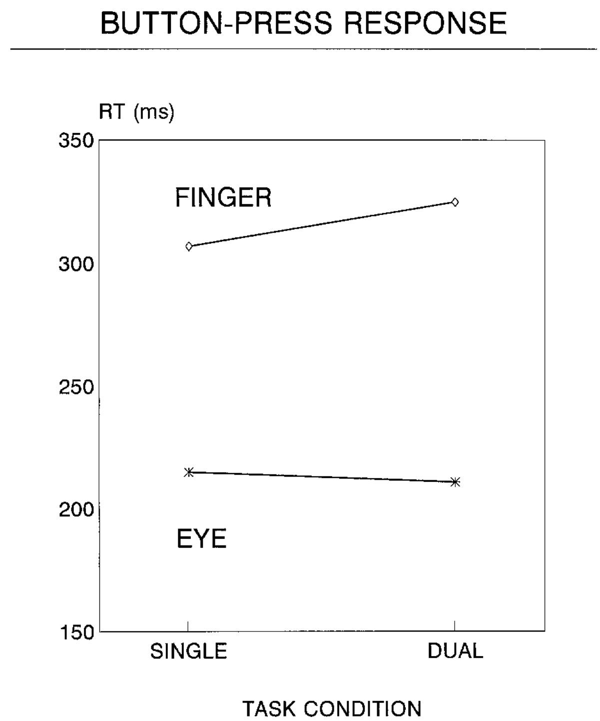

Fig. 2. Mean RT latencies (ms) of eye and button-press responses in both single- and dual-task conditions (experiment 2). Saccadic eye RT latencies and button-press RT latencies are similar in single and dual-task conditions

The most important result of experiment 2 was the absence of a significant interaction effect between type of movement (eye vs finger) and task condition (single vs dual), ($F_{(1,11)}=0.6$, $p>0.2$).

Discussion

The purpose of experiment 2 was to investigate whether the interference effect between the eye and hand response observed in experiment 1 was due to specific or non-specific interference. The finding that saccadic eye movements and button-press responses in the dual-task condition could be initiated without delay relative to the single-task conditions, supports the specific interference interpretation.

General discussion

The experiments reported here produced three major findings. Experiment 1 showed the absence of a *temporal order effect*. There were no significant differences between the RT latencies of eye and hand in the dual-task condition. This experiment also demonstrated an *interference effect*. There was an increase in saccadic eye RT latencies in the dual-task relative to the single-task condition. Experiment 2 showed a *task-specific effect* i.e. there was no increase in either the saccadic or button-press RT latencies in the dual-task relative to the single-task condition.

Temporal order

The common finding in the literature of dual-task conditions involving eye-hand coordination movements to a target is that the eye starts to move in the direction of the target before the hand (see Introduction for references). The discrepant finding reported in experiment 1 seems to indicate that this order of eye and hand responses may be due to the specific task requirements. Traditionally, experiments on eye-hand coordination have involved a relatively small target – for example, a light-emitting diode – which, because of the need for precise foveal information to guide the hand accurately to the desired end position, may invoke serial order operation of eye and hand motor systems. In experiment 1, such stringent demands were not imposed on subjects. Speed and not accuracy of both eye and hand movements was stressed and, to this end, large targets were used and only two possible target positions employed. The absence of a temporal order effect in the present dual-task condition calls into question the generality of the eye-first, hand-second phenomenon. In their first experiment, Abrams et al. (1990) found that subjects spontaneously executed a saccade toward the target of their rapid aimed limb movements but that only three of four subjects tested began to move their eyes first. They phrased this finding as "The saccade is closely time locked to the initiation of the limb movement, although its order of occurrence does not seem crucial: limb movements (e.g., wrist rotation) are equivalent whether they lead or follow an eye movement" (p. 254). The actual movement order therefore may depend on the behavioural task involved, as for instance the amount of uncertainty about the spatial location of the target.

The finding that saccadic eye movement latencies were slightly larger in the experiments reported here than those to be found in the literature can probably be accounted for by the fact that most researchers extinguished the fixation light at the moment the target appeared. This extinction has been shown to provide an extra cue that reduces saccadic latency (e.g. Reulen 1984). Other investigations within a so-called overlap paradigm showed saccadic RT latencies of the same order (e.g. Fischer and Rogal 1986).

Task-specific interference effect

The fact that no increase in RT latencies was observed either for the eye or for the hand in experiment 2, where finger-press responses were required, suggests that the observed interference effect of experiment 1 is restricted to situations in which both hand and eye are functionally involved in moving to a target position.

In a related study done with eye and hand movements within a dual-task paradigm, Fischer and Rogal (1986) found saccadic eye latencies to be independent of whether or not they were combined with hand movements. However, in contrast to the present study they used small targets (1 deg × 1 deg). This task constraint may induce subjects to first move the eyes first to the target position and subsequently the hand; in other words, small targets may demand serial operation of ocular and manual motor systems, while large targets may demand parallel operation. Frens and Erkelens (1991) also concluded that, depending on the task constraints, coordination of hand and eye movements involves parallel and independent control, or the sharing of specific processes.

Both the finding that eye and hand RTs were not significantly different from each other in the dual-task condition and the finding that none of the subjects showed a significant correlation between eye and hand RTs indicate that the augmentation of saccadic eye RTs in the dual-task relative to the single-task condition is not due to an eye-is-waiting-for-the-hand phenomenon. Further research is being carried out in our laboratory to investigate the nature and locus of the delay that ensues when saccadic eye responses are combined with goal-directed hand movements.

Because saccades have stereotyped velocity profiles and because they show quick orienting behaviour under all kind of circumstances, the saccadic system has often been considered to be an automatically reacting open-loop system (e.g. Carpenter 1988; Posner et al. 1978; Prablanc and Pelisson 1990; Young and Stark 1963); clearly, the results of experiment 1 in which a significant increase in saccadic RT latency was observed in the dual-task condition call the generality of this conceptualization into question.

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