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Research Report

Dual-tasking: Is manual tapping independent of concurrently executed saccades?

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ABSTRACT

Maintaining both spatial and temporal accuracy of concurrent motor actions is a challenging behavioral requirement in multi-tasking, where possible resource bottlenecks may become apparent when these units are shared between tasks. This study addresses the question of whether periodic self-paced finger movements (tapping) compulsorily interact with concurrently executed saccades, because they share some common neural control pathways. We employed a dual-task paradigm which was previously used to demonstrate strong interference between independent but concurrently conducted bimanual tapping tasks (Wachter, C., Cong, D.K., Staude, G., Wolf, W., 2008. Coordination of a discrete response with periodic finger tapping, additional experimental aspects for a subtle mechanism. J. Motor Behav. 40, 417–432). Instead of the discrete left hand response, the 13 participants now executed a single saccadic eye movement to a fixed visual target in parallel to continuous periodic tapping of the dominant hand. We expected these reactive saccades to act as a strong perturbation event to the continuous tapping, but the experimental data did not reveal a considerable interference in this specific oculo-manual dual-task experiment.

1. Introduction

A fascinating example of multi-tasking is the one-man band — this musical tradition demonstrates the amazing capability of humans to execute several parallel actions with reliable spatio-temporal accuracy, which requires a high degree motor coordination between different effectors. The coordinative process is so naturally governed by the central nervous system that many of our daily multi-tasking activities seem to be effortless and easy. However, while musicians are trained to perform more than one task simultaneously, normal individuals dealing with some dual- or multi-tasking are usually troubled; e.g., bimanual interference is found when two manual tasks are conducted concurrently (e.g., Swinnen and Wenderoth, 2004). Dual-task costs (i.e., decreased performance in comparison to isolated execution of the tasks) were found not only in bimanual but also in other dual-task combinations (Pashler et al., 1993; Sigman and Dehaene, 2008). Favoring a serial organization of sensorimotor transformation stages (perception, cognition and action) within a single channel, some researchers (Welford, 1967; Pashler, 1994; Pashler and Johnston, 1989) attributed dual-task costs to a central bottleneck at the response-selection stage, which is assumed to be generic (e.g., Hazeltine and Ruthruff, 2006), whereas others (Logan and Gordon, 2001; Navon and Miller, 2002) addressed the limitations of strategic allocation of the

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central resources (for a more extended review, see Hazeltine et al. 2006).

Indeed, strong interference in dual-tasking has been demonstrated more recently in *bimanual finger tapping* (e.g., Yoshino et al., 2002; Wachter et al., 2004, 2008). Tapping is a convenient task to address issues of explicit representation of passage of time, i.e., explicit timing (Zelaznik et al., 2002). In these bimanual studies, a dual-task paradigm (Fig. 1) required participants to perform repetitive down–up movements (tapping, see Repp, 2005 and Wing, 2002, for review) with the index finger of the dominant hand, while they also were required to respond as fast as possible to randomly interspersed stimuli with a discrete single tap of the non-dominant index finger. It was found that the rhythmic task affected the timing of the discrete response and vice versa. However, it has remained unclear whether this interaction is *effector-specific* or *task-specific*.

Therefore, an alternative dual-task paradigm combining such seemingly unrelated movements as manual (periodic tapping) and eye movements (goal-directed saccade) is of specific interest in this context, since possible perceptual and movement production bottlenecks (De Jong, 1993) as well as cross-talk (Navon and Miller, 1987) may be avoided in a way that the stimuli (visual and auditory) as well as the required responses (saccade and finger tapping, respectively) for the two tasks engage different modalities. In most cases the nature of the coordination between eyes and hands has been studied for visually guided manual actions (for review, see Jeannerod, 1988; Binsted and Elliot, 1999; Crawford et al., 2003), with the general finding that ocular and manual reaction times mostly co-vary. When directed to the same target, both movements tend to start almost simultaneously (Fisk and Goodale, 1985); also, temporal characteristics of saccades are influenced by arm kinetics (Snyder, 2000; Lunenburger et al., 2000; Snyder et al., 2002; van Donkelaar et al., 2004). Moreover, Fox et al. (1985) revealed that the execution of saccades and finger movements activates overlapping cortical areas: both of them recruit the supplementary motor area and the cerebellum. Neural activity in the (saccade related) superior colliculus and in the (limb movement related) posterior parietal cortex is modulated by limb (Stuphorn et al., 1999) and eye position changes, respectively (Snyder, 2000). In an imaging study, Bedard et al. (2008) observed modulation of (visually-cued) finger tapping related brain activity for different static gaze directions. This and more recent results (Bedard and Sanes, 2009) further extend findings on brain areas with combinatorial effects of static gaze direction and finger movements. Taken together, it is consequent to ask what happens when these two effectors (eyes and hands), now not sharing a target, are acting independently but concurrently.

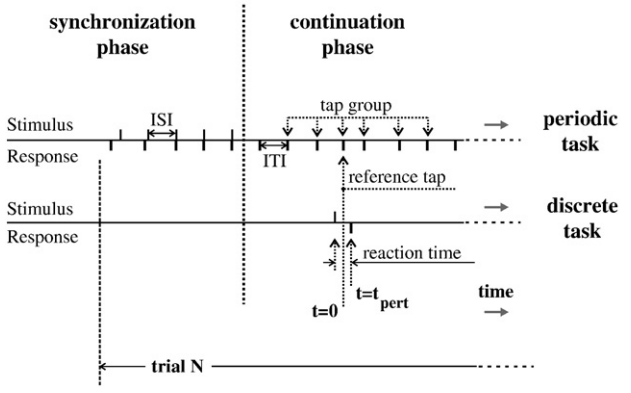

Fig. 1 – A schematic overview of the dual-task paradigm: Sensorimotor events are indicated by the short vertical lines. For each task, the stimulus and the motor response events are depicted as a function of time. In the periodic tapping task, inter-stimulus interval (ISI) of the audio pace (given only in the synchronization phase) was 600 ms; the resulting tapping was characterized by the intertap interval (ITI). The discrete task events are shown below: in the continuation phase, random go-signals were responded with discrete responses (with saccades in the oculo-manual dual-tasks and discrete left hand taps in the bimanual dual-tasks). Reaction time was a measure of the speeded discrete task. The periodic tap just ahead of the discrete motor response was defined as the reference tap. It set t=0 within this response frame and also served for determining the normalized phase by Eq. (1). The interval between the reference tap and the perturbation event is t_{pert}. The six periodic taps around the reference tap marked as "tap group" are usually selected for the construction of the phase resetting curve diagrams.

In everyday behavior, there are many cases when the hands perform discrete and/or repetitive movements while the eyes are directed elsewhere. However, only few studies have explored eye–hand interaction in different dual-task situations (e.g., Bekkering et al., 1994; Pashler et al., 1993; Claeys et al., 1999; Stuyven et al., 2000), and their results are ambiguous. In dual-task paradigms with two discrete tasks (manual reaction and saccade, e.g., Bekkering et al., 1994), oculo-manual interference was found in case of targets being unpredictable in time and space but not in case of some degree of predictability. Dual-task paradigms with combination of periodic and discrete tasks were also used (e.g., Claeys et al., 1999; Stuyven et al., 2000) and showed some general small increase of saccade latency due to the secondary (tapping) task, but, unfortunately, the tapping behavior was not analyzed. This demonstrates that the issue of interference between eye and hand movements has remained controversial. On the one hand, since both effectors share some common brain structures, oculo-manual interaction effects in dual-task conditions would not be surprising. On the other hand, this sharing of common networks must not necessarily be effective in all dual-task situations but can be redundant (i.e., not basically necessary for the dual-task execution) allowing some independence of the two tasks. Therefore, our study addresses the question of whether the strong dual-task interaction found in bimanual finger tapping experiments is also present in an equivalent oculo-manual dual-task condition.

2. Results

An outcome of the dual-task experiments was evaluated by means of phase resetting curves (PRCs, Yoshino et al., 2002) which contain the information about the timing of the motor actions in the dual-task experiment (details of PRC construction