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Eliminating dual-task costs by minimizing crosstalk between tasks: The role of modality and feature pairings

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ABSTRACT

We tested the independent influences of two content-based factors on dual-task costs, and on the parallel processing ability: The pairing of S–R modalities and the pairing of relevant features between stimuli and responses of two tasks. The two pairing factors were realized across four dual-task groups. Within each group the two tasks comprised two different stimulus modalities (visual and auditory), two different relevant stimulus features (spatial and verbal) and two response modalities (manual and vocal). Pairings of S–R modalities (standard: visual–manual and auditory–vocal, non-standard: visual–vocal and auditory–manual) and feature pairings (standard: spatial–manual and verbal–vocal, non-standard: spatial–vocal and verbal–manual) varied across groups. All participants practiced their respective dual-task combination in a paradigm with simultaneous stimulus onset before being transferred to a psychological refractory period paradigm varying stimulus-onset asynchrony. A comparison at the end of practice revealed similar dual-task costs and similar pairing effects in both paradigms. Dual-task costs depended on modality and feature pairings. Groups training with non-standard feature pairings (i.e., verbal stimulus features mapped to spatially separated response keys, or spatial stimulus features mapped to verbal responses) and non-standard modality pairings (i.e., auditory stimulus mapped to manual response, or visual stimulus mapped to vocal responses) had higher dual-task costs than respective standard pairings. In contrast, irrespective of modality pairing dual-task costs virtually disappeared with standard feature pairings after practice in both paradigms. The results can be explained by crosstalk between feature-binding processes for the two tasks. Crosstalk was present for non-standard but absent for standard feature pairings. Therefore, standard feature pairings enabled parallel processing at the end of practice.

1. Introduction

In every-day life there are situations in which we wish or try to do two things at the same time. In dual-task research the question whether we can process two tasks in parallel is still a matter of debate. The vast majority of parallel-processing research established that people get slower and/or more error prone at one or both tasks when they try to perform them at the same time compared to their performance in a single task context (e.g., Carrier & Pashler, 1995; Hommel, 1998a; Pashler & Johnston, 1989; Ruthruff, Johnston, Van Selst, Whitsell, & Remington, 2003; Van Selst & Jolicoeur, 1994).

One important theoretical explanation of dual-task costs is the assumption of a *response-selection bottleneck* (Pashler, 1984). In this view, processing of simple choice tasks can be broken down into a chain of three discrete, subsequent processing stages: stimulus encoding (sensory stage), response selection (central stage), and response execution (motor stage, Sternberg, 1969). The central processing stage, that is, the translation of stimulus information into a response according to task demands, is constrained to one process at a time (i.e., there is a central bottleneck). The sensory and motor stages can run in parallel for two tasks as long as they don't compete for the same sense organs or motor effectors.

A strong version of the bottleneck theory states that the bottleneck cannot be overcome by practice (Ruthruff et al., 2003). This assumption is challenged by findings showing no dual-task costs after practice (Allport, Antonis, & Reynolds, 1972; Hazeltine, Teague, & Ivry, 2002; Oberauer & Kliegl, 2004; Shaffer, 1975). One well-controlled study showing this result was conducted by Schumacher et al. (2001). In one task of their study people had to press one of three spatially compatible buttons on the computer keyboard according to the location of a visually presented disc. In

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the other task participants heard one of three possible tone pitches, which they had to categorize by saying aloud "one", "two", or "three". Dual-task costs in reaction times (RTs) and percent errors (PEs) were minimal or even vanished at the end of practice. The authors interpreted their results as showing parallel processing of two tasks.

Levy and Pashler (2001) questioned the generality of this interpretation and pointed to the specific stimulus–response modality pairings as one cause for minimal dual-task costs. In their first experiment they replicated the results of Schumacher et al. (2001) using their visual–manual and auditory–vocal task combination. However, when interchanging the stimulus–response modality pairings in a second experiment, such that participants had to respond with a key press to the pitch of a tone (auditory–manual task), and give a vocal response to the location of a circle (visual–vocal task), considerable dual-task costs were observable.

1.1. The effect of modality pairings on dual-task costs

The comparison of the two experiments of Levy and Pashler (2001) provided a first hint that the modality pairings of stimuli and responses influence whether dual-task costs can be eliminated with practice. Further research mainly focused on the finding that modality pairings affect the magnitude of dual-task costs more than they affect single-task performance (Hazeltine & Ruthruff, 2006; Hazeltine, Ruthruff, & Remington, 2006; Stelzel, Schumacher, Schubert, & D'Esposito, 2005). For example, Hazeltine and Ruthruff (2006) had one group respond with a left or right key press to the visually presented symbols '#' and '%', and say "one" or "two" to the presentation of two possible tone pitches, that is, they combined a visual–manual with an auditory–vocal task. These stimulus–response modality pairings (modality pairings) are denoted as *standard* (M+) in the following. For the other group the tasks demanded to press a left or right key according to the pitch of a tone, and to say "one" or "two" according to the visual symbols '#' or '%', that is, an auditory–manual task was combined with a visual–vocal task. These modality pairings are denoted as *non-standard* (M−). Whereas modality pairings only slightly affected single-task performance, dual-task costs were significantly higher for the non-standard compared to the standard modality pairings. Hazeltine and Ruthruff (2006) proposed interference between the central operations as the cause of higher dual-task interference in non-standard compared to standard modality task-pairs.

The aims of the present study are to further examine the effect of modality pairings on dual-task costs, and to investigate under which conditions dual-task costs vanish after practice. We argue that the effect of modality pairings on dual-task costs is best understood within the framework of the *theory of event coding* (TEC, Hommel, Müsseler, Aschersleben, & Prinz, 2001) with its *common coding* principle (Prinz, 1990), as we explain next. In Section 4 we will consider the implications of our findings for alternative theories of dual-task costs, such as the bottleneck theory (Pashler, 1984) and resource-sharing accounts (Navon & Miller, 2002; Tombu & Jolicoeur, 2003; Wickens, 1980).

The common coding principle states that stimuli and responses are represented by features in a common domain. Many kinds of features (e.g., "left") can represent aspects of a distal event, and thus are applicable to both stimuli (e.g., a flashing light on the left) and responses (e.g., pressing the left key). Relevant features of perceptual events and the accompanying actions are activated and bound together according to the current task rules. Stimulus and response representations of a task can overlap to varying degrees within the common medium of representation. For instance, responding to a visual stimulus at a spatial location with a manual response directed to a location in space implies that stimuli and responses overlap with regard to spatial features (Hommel et al., 2001; Kornblum, Hasbroucq, & Osman, 1990). Overlap between stimulus and response features in the same representational medium facilitates bindings between them (Kornblum et al., 1990).

In a dual-task context two bindings have to be established: The stimulus and the response features of each of two tasks are activated. This situation raises the "binding problem" (Logan & Gordon, 2001, p.398): The stimulus features of Task 1 (S1) need to be bound to the response features of Task 1 (R1), and S2 need to be bound to R2. In this situation, crosstalk can arise, such that S1 is bound to R2, and S2 is bound to R1. The chance of crosstalk depends on the overlap between stimulus and response features within each task, and their overlap across tasks. When there is overlap within tasks (i.e., S1 and R1 overlap, and S2 and R2 overlap), but not across tasks, the overlap facilitates the correct bindings, reducing the risk of crosstalk. In contrast, if there is overlap across tasks, but not within tasks (i.e. S1 overlaps with R2, and S2 overlaps with R1), the risk of crosstalk is high, because the overlap encourages bindings across tasks. This constellation is expected to exacerbate dual-task costs (Koch, 2009).

1.2. Crosstalk between stimulus and response representations of two tasks

Combining two tasks with standard modality pairings (i.e., an auditory–vocal and a visual–manual pairing) facilitates binding each stimulus to the correct response because stimulus and response representations overlap to a larger degree within tasks than across tasks. Auditory stimuli and vocal responses share sound features: The task is to discriminate sounds and to produce other sounds in response. Visual stimuli and manual responses share spatial features: The task is to discriminate visual events in space, and respond by a manual movement to a spatially defined location (usually, the location of a response key). For instance, in Experiment 1 of Schumacher et al. (2001) the spatial features of the visual stimuli had to be translated into a compatible spatial response. Likewise, the tones had to be responded with a sound response. Hence, there was little feature overlap between stimuli of one task and responses in the other task when both tasks have standard modality pairings, and therefore there is hardly any risk of cross-task interference during binding. Their binding processes could work without conflict.

Crossing these modality pairings to create non-standard modality pairings, as in Experiment 2 of Levy and Pashler (2001), produces a situation where the stimulus alternatives of one task and the response alternatives of the other task share verbal-sonic and spatial features. In the visual–vocal task the spatial features of the visual stimuli had to be translated into the production of verbal sounds. In the auditory–manual task the identification of a sound had to be translated into a spatial response (e.g., left or right key press). Thus, in the non-standard modality-pairing condition spatial and sound features belong to both tasks. This increases the risk of crosstalk, that is, the confusion of S and R features across tasks. When the risk of crosstalk is high, the cognitive system needs to temporally disentangle the two tasks by carrying them out sequentially (Logan & Gordon, 2001). This might be the basis for the higher dual-task costs for task combinations with representational overlap across tasks (M−) compared to task combinations without representational overlap (M+).

1.3. The present study

Our aim is to further examine the role of features in the effect of modality pairings on dual-task costs. The effect of modality pairings reported in the literature so far can be explained by postulating that auditory stimuli and vocal responses overlap in a shared representational medium for verbal and sonic features, whereas