



## Editorial



## Interference between cognition and motor control in human multitasking: An editorial

A broad definition of multitasking, as a condition in which cognitive processes involved in two or more tasks overlap in time, means that a wide range of research paradigms in the domains of human cognitive psychology and movement sciences will be included in this definition (Kiesel et al., 2022; Koch et al., 2018). Research into human multitasking, and in particular into cognitive and motor multitasking, has constantly been a focal point of scientific enquiry in psychology in the past decades. It is fair to say, however, that international research efforts have intensified even more in recent years as it is understood that an individual is required to meet multitasking demands in almost every facet of daily living. This applies to both healthy individuals as well as patients with disabilities caused by neurological impairments, who might experience severely impaired multitasking capabilities. Therefore, we expected for this special issue individual manuscript submissions from international colleagues reporting on a wide spectrum of research related to cognitive and motor multitasking. Indeed, our expectations were met so that this special issue comprises 19 articles, including 3 reviews and meta-analyses and 16 research papers, covering current research into a diverse range of thematic issues such as cognitive task switching, motor sequence learning and motor action effects, cognitive-motor dual-task interference, effects of physical exercise and effects of fatigue.

The ability to switch between tasks can be considered the focal point of many activities in daily living, both at work or at home. Task switching is costly but is also a basic requirement of any contextual adaptability of us humans. Four articles focussed on task switching paradigms such as voluntary and reactive task switching. Broeker et al. (2022) investigated voluntary task switching in the motor dual-task context of a typing task and a concurrent manual tracking task. In order to adopt a wider perspective in terms of interindividual differences, they related performance in terms of reward-dependent switch rates and the time on task to their participants' personality characteristics such as risk tendency and impulsivity. However, the authors did not find either of the two personality traits to act as reliable predictors of switching choices. Langhanns et al. (2021) utilized a voluntary task switching paradigm in which the physical effort required for any motor responses to a cognitive task increased with task repetitions while the physical effort for task switches was low. Thus, participants had to take into account both cognitive switch costs and motor repetitions costs when deciding whether or not to pursue the same task on consecutive trials. The authors confirmed that voluntary task switching is influenced by both cognitive and motor costs indeed. With respect to reactive task switching, Nolden and Koch (2022) reported the results of an auditory task-switching paradigm that required the classification of the pitch or the loudness of a tone as either high or low. Comparing two experiments,

the response sets for each auditory classification were either overlapping in the manual modality or were task-specific in terms of the requirement to respond manually or vocally. Switch costs were not affected by response overlap but congruency effects were reduced when response sets did not overlap. Stephan et al. (2022) assessed the effects of compatibility between the modalities of a stimuli and responses in a task switching context. Their aim was to test the transfer benefit of short-term learning or habituation to compatible or incompatible modality mappings in a single task situation to performance in a task-switching situation with regular switches between compatible and incompatible mapping. They found that a preceding single task practice session with incompatible mappings abolished switch costs in the dual-task situation. They concluded that acquired modality compatibility mappings and the resultant cross-talk can be modulated in short-term by task-specific associations.

The question whether performance reward influences dual-tasking was touched on by two manuscripts. Raßbach et al. (2021) assessed predictions of embodied choice models that an ongoing action has a direct effect on value-based decision making. By the implementation of a visual multi-lane tracking task, in which participants needed to switch the position of a cursor between lanes to avoid obstacles or to collect rewards, motor control demands were manipulated by external, directional perturbations on the cursor. The expectation was that perturbation-compensation efforts would affect the direction of subsequent reward-targeted decision making. The predictions of embodied choice models were confirmed, demonstrating that participants tried to minimize action cost in the context of associated rewards, with the addition, however, that also the current state of the cursor interacted with decision making. Using a Psychological Refractory Period paradigm, Langsdorf, Goehringer, et al. (2022) investigated whether performance reward could alter the reaction time delay of a secondary task caused by sequential processing at a response selection bottleneck in dependency on stimulus onset asynchrony. The authors did not assume that reward would affect the structural bottleneck itself but that reward would shorten either the pre-bottleneck or post-bottleneck processing and therefore result in shorter response times in the secondary task. This pattern of results was expected to express itself in terms of an interaction with the stimulus onset asynchrony (SOA) in the case of trials with pre-bottleneck reward effects. They observed that administration of a reward influenced pre-bottleneck stages of the first task and that this performance enhancement propagated to the response selection stage of secondary task.

The acquisition of knowledge about the regularity of action sequences is a basic mechanism that enables humans to optimize any interaction with an individual's environment. Three articles adopted

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research questions that centred on the learning of sequences in environmental stimuli. [Leh et al. \(2022\)](#) investigated sequence learning in a serial reaction time task of the distal upper extremity using movement direction-related changes in electromyographic activations of specific arm muscles as a performance outcome parameter instead of purely chronometric measures. They observed that muscle activations not only confirmed known learning effects regarding speeded sequence reproduction, they also convey information on the certainty with which participants responded to the stimuli. [Röttger et al. \(2021\)](#) investigated if a predictable sequence of stimulus onset asynchronies (SOA) between two conflicting tasks would facilitate performance by the learning of recurring demands on task-shielding for the prevention of interference. They observed, however, that a predictable SOA sequence did not alter interference effects during short SOAs and therefore expresses a limitation in the abilities to adapt to impending cognitive task conflict. [Pelzer et al. \(2022\)](#) proposed that dual-task costs might be the result of cross-talk on the level of integrated task-sets. To test this assumption, they investigated the influences of action effects and error feedback on sequence learning under dual-tasking conditions as manipulations that were supposed to alter integration of two tasks into a single set. Conjoined error feedback reduced sequence learning during dual-tasking, while separate action effects did not. The authors' observations suggest that task-set integration is the standard case in a dual-tasking but can be modulated by separation of action effects.

The monitoring of effects of actions and subsequent adjustments in behaviour was thematized in two articles of this special issue. [SchAAF et al. \(2022\)](#) conducted three experiments to test if the instructed relevance of any action effects influences the monitoring of the effects of an action in a dual-task setting. Although irrelevant action effects showed lower monitoring costs, the results indicate that irrelevance cannot serve as an exclusion criterion from action effect monitoring. Monitoring the effect of an action is also relevant for visuomotor adaptation. [Langsdorf, Kübler, and Schubert \(2022\)](#) investigated whether a secondary auditory-verbal 1-back task would affect both the explicit and implicit components of visuomotor adaptation in a centre-out manual reaching task with rotated visual feedback. Their expectation was that the explicit component of adaptation would be affected by dual-tasking distraction, while the implicit component would remain unaffected during practice and in the post-exposure period. In contrast to their expectations, however, dual-tasking load only changed performance in the practice phase but not in the post-exposure, aftereffect period. Their findings suggest that dual-tasking leads costs in terms of reduce motor performance in a visuo-motor adaptation task but not motor adaptation itself.

Four articles touched on the issue of cognitive-motor interference during dual-tasking. [Löhr-Limpens et al. \(2022\)](#) studied cognitive-motor interference during dual-tasking in the context of object-directed grasp-and-place task. They hypothesized that distraction by an auditory n-back task would differently affect planning and programming of the motor task. In two experiments, they observed reductions in cognitive performance by dual-tasking as well as indications that motor planning but not programming involves cognitive resources. A more applied point of view was taken by [Amico and Schaefer \(2022\)](#) who examined the role of expertise in a sports discipline (tennis) on dual-task costs in a context, where the sport has to be performed in combination with a working memory demanding cognitive task. They observed that players with greater motor skills demonstrated lesser dual-tasks costs in the cognitive domain and greater amount of performance facilitation in the motor task during dual-tasking compared to less able players of intermediate skill levels. A similar approach was also pursued by [Amico and Schaefer \(2022\)](#), who contrasted the performance of table tennis experts and novices in dual-tasking conditions depending on whether the tasks of the concurrent cognitive-motor activity were self-initiated or externally timed, expecting greater dual-task costs in self-initiated tasks. Experts demonstrated lesser dual-task costs than the novices but also the tendency for slightly greater costs when the tasks involved were self-initiated, whereas the novices showed the opposite relationship. In

both papers, [Schaefer and Amico \(2022\)](#) suggested that cognitive-motor dual-task costs may be directly related to sensorimotor expertise for a specific sports activity. [Patterson and Kahan \(2022\)](#) investigated the research question if working memory load alters any cognitive interference induced by both the occurrence of alerting cues and the congruency or incongruency of distractors with a required response as in flanker task. However, they did not find any evidence for an influence of working memory load on the effect of an alerting cue or the congruency of the distractors and therefore proposed a theoretical account according to which distractors act via an automatic processing route, which benefits from alerting cues but does not require working memory resources.

Can cognitive performance be affected by specific types of physical and postural activities? This question was addressed by two articles. [Straub et al. \(2022\)](#) were concerned with postural effects on cognition and reported two replication experiments as well as performed a meta-analysis on conflicting research, in which it was argued that cognitive control is facilitated by a standing posture compared to sitting. Both their replication attempts and the meta-analysis led the authors to conclude that the influence of body posture on cognitive control cannot be taken as a robust finding. [Knatauskaitė et al. \(2022\)](#) aimed to better understand the mechanisms behind the association between physical exercise and subsequent short-term changes in cognitive performance in adolescents. Three groups of teenagers were sorted into a control group without any exercise and two groups that received either light or vigorous physical exercise. Performance in an information processing task and Testosterone and Cortisol hormone levels were assessed before and after 20-min of exercise. No training-related effects on cognition were found as all three groups showed performance improvements in the cognitive task after the intervention period. Increases in Cortisol levels were raised and correlated with cognitive performance only after vigorous exercise.

Two articles took the broader view and conducted a literature review on aspects related to movement control and mental processes. [Wollesen et al. \(2022\)](#) reported the results of a literature review on the effect of cognitive-motor dual-tasking training on cognitive and physical performance in children and adolescents. Their conclusion was that current evidence in the literature supports task-specific benefits of cognitive-motor dual-tasking training on single-task cognitive or motor performance, especially with respect to the functional domain of balance control. Due to the inconsistency between found intervention studies, no "best practice" recommendations are possible at this point in time, unfortunately. Finally, [Brahms et al. \(2022\)](#) reported the results of a systematic review and meta-analysis of the effect of mental fatigue on balance control in dependency on aging. They found combined evidence for only a small effect of mental fatigue after performing a cognitive task on the control of body balance. This general effect does not seem to be moderated by the aging or the difficulty of the balancing task.

To conclude, this special issue provides a comprehensive overview of current research into multitasking involving cognition and the control of movements and it gives us a sense of direction where future research ought to be headed. By classifying the research presented in all articles of this special issue according to the taxonomy proposed by [Koch et al. \(2018\)](#), we conjecture that the current focus of multitasking research has shifted away from a structural perspective, which favours an account of information processing stages and local capacity limitations influencing the capability for multitasking, towards the perspectives of flexibility and plasticity in human multitasking. Flexibility in multitasking refers to the ability of human behaviour to adapt to new situations and tasks, for example in terms of task switching. The plasticity perspective, on the other hand, encompasses the internal cognitive reorganization for task-specific optimization of behaviour and performance by processes of learning and training in multitasking situations. Thus, in terms of future directions of research into human multitasking, this special issue also offers an impression of the terrain that still needs to be covered and the difficulties that may await the researcher when traversing this domain.

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