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Table tennis expertise influences dual-task costs in timed and self-initiated tasks

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ABSTRACT

Theories on resource sharing predict that performances will suffer under dual-task conditions. However, increases in skill level should decrease attentional resources needed to perform a task, resulting in a reduction of dual-task costs. The current study investigates whether table tennis experts are better able than novices to keep up their motor and cognitive performances in a dual-task situation. Two different cognitive tasks, 3-back and Counting Backwards in steps of 7, and two different table tennis tasks, returns and serves, were assessed in each possible cognitive-motor task combination in a within-subjects design. While 3-back and returns were timed, Counting Backwards and serves were self-initiated. We assumed that self-initiated tasks increase dual-task costs, since the scheduling of the responses requires attentional resources. As predicted, dual-task costs of novices were considerably higher (35%) than those of experts, who did not show costs (−1%). The predicted increase of costs for self-initiated tasks was only observed in the experts, while novices showed a tendency to reduce their dual-task costs for self-initiated tasks. It is argued that this is due to the psychometric properties of the underlying task, since timed tasks were specified by a fixed number of targets and responses. We conclude that cognitive-motor dual-task costs may be a valuable measure of sporting skill, over and above "pure" motor or cognitive performances.

1. Introduction

Multitasking is common in everyday life. We walk down a flight of stairs while talking to a friend, or we throw an object into the trash can while listening to the radio. In these situations, a cognitive task is performed simultaneously with a motor task. The need to coordinate motor and cognitive functions is also prevalent in many sporting contexts. Athletes in dynamic team sports like soccer, basketball or hockey need to perform sophisticated dribbling, aiming or shooting tasks while keeping an eye on the position of their opponents, in order to arrive at optimal strategic decisions. These situations require attention (Abernethy, 2001; Schneider & Shiffrin, 1977), anticipation (Loffing & Canal-Bruland, 2017; Müller & Abernethy, 2012), working memory (Buszard et al., 2017; Furley & Memmert, 2010), and decision making (Baker et al., 2003). Experienced athletes are more successful than novices to handle these challenges, which is one reason why they outperform others on the playing field.

Theories on motor skill learning (Adams, 1971; Gentile, 1972; Fitts & Posner, 1967) predict that the initial stages of skill acquisition require more cognitive resources/attention than later stages. After sufficient practice, the skill can be executed in an automatized manner, and cognitive effort is reduced. Dual-process theories assume that human behavior can be run either by Type 1 processes, which are independent from attentional control, or by Type 2 processes, which depend on cognitive processing resources, like attention and working memory capacity (Evans & Stanovich, 2013; Kahneman, 2011; Shiffrin & Schneider, 1977). Furley et al. (2015) have introduced this account to the field of sport. They argue that default-interventionist models, a subgroup of dual-process theories, may be particularly useful to describe behaviours in complex sport situations: Type 1 processes are activated by default, and Type 2 processes only take over when Type 1 processes do not enable the athlete to find a solution. We argue that task practice leads to automatized motor skills, representing Type 1 processes in skilled athletes. Novices, who are still in the process of learning the skill, require Type 2 processes (attention, working memory) to perform the motor skill.

In a cognitive-motor dual-task situation, attention has to be shared between the two domains. For sport-specific task combinations,

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numerous studies report the predicted performance advantages of experts (Abernethy, 1988; Beilock, Carr, et al., 2002; Beilock, Wierenga, and Carr, 2002; Beilock et al., 2004; Castiello & Umiltà, 1988; Gabbett et al., 2011; Gabbett & Abernethy, 2013; Gray, 2004; Leavitt, 1979; Parker, 1981; Smith & Chamberlin, 1992; Vuillerme & Nougier, 2004; Vuillerme et al., 2001) in a variety of sports (golf putting, baseball, rugby, soccer, track and field, ice hockey, or gymnastics). However, study designs vary considerably. Some studies have used discrete stimuli (i.e. reaction time tasks, throwing a ball at a target), while others required continuous performances (i.e. running, maintaining posture, skating, working memory updating). In addition, studies often used the primary-/secondary task approach (Abernethy, 2001), instructing participants to keep up their motor task performance under dual-task conditions, and using the (secondary) cognitive task primarily to "disturb" the execution of the motor task. Single-task baseline performances for cognition are often not measured in these paradigms (Beilock, Carr, et al., 2002; Beilock et al., 2004; Gray, 2004; Leavitt, 1979; Parker, 1981; Smith & Chamberlin, 1992), and subjects sometimes fail to keep up their motor performances in the dual-task situation (Abernethy, 1988; Gray, 2004; Leavitt, 1979; Parker, 1981). Due to this lack of methodological consistency, it is difficult to arrive at clear conclusions. We argue that performance changes from single-to dual-task conditions should be measured for both task domains (Li et al., 2005; Schaefer, 2014). This allows for the calculation of dual-task costs, which express performance decrements in relation to each individual's baseline performance (Somberg & Salthouse, 1982). Specific task characteristics can influence trade-off patterns between two concurrent tasks. For example, in an age comparative context, a higher degree of visual demands of the non-walking task increased age differences in dual-task costs (Bock, 2008). In addition, the predictability and relative timing of experimental stimuli influence dual-task performances. Broeker et al. (2021) combined a continuous tracking task with a reaction-time task and systematically varied the predictability of the two tasks. Participants were only able to re-invest cognitive resources into the unpredictable task if the stimuli of the two tasks were "coupled" in a meaningful way. The current study therefore varies the temporal structure of the component tasks, by using different combinations of timed and self-initiated tasks.

A recent study asked expert and novice table tennis players to perform a working memory task, 3-back, while returning balls from a ball machine (Schaefer & Scornaienchi, 2020). For the cognitive task, participants had to compare the number that they hear to the number presented three positions earlier in the sequence. Balls and numbers were either presented concurrently, or one after the other (ball - number - ball – number…). The alternating stimulus presentation was assumed to be easier, since participants do not have to respond to two stimuli in the same time-window, avoiding central or peripheral processing bottlenecks (Broadbent, 1958; Pashler, 1994; see also Abernethy, 2001). Experts and novices did not differ in 3-back performances under single-task conditions. Cognitive dual-task performance reductions were more pronounced in novices. A similar pattern emerged for the number of missed balls in table tennis, except that experts outperformed novices already in the single task. Experts consistently showed costs of about 10%, while novices showed costs between 30% and 50%. However, there were no differences between costs in the alternating stimulus presentation condition, as compared to the simultaneous condition. The findings indicate that performances of novices suffer considerably in motor-cognitive dual-task situations.

The Schaefer and Scornaienchi (2020) study used tasks that require responses in fixed time-windows. To our knowledge, there is no study that has systematically combined timed and self-initiated tasks in a cognitive-motor dual-task situation in a sports setting. Therefore, the current study aims to replicate and extent previous findings, by adding two self-initiated tasks that provide opportunities to strategically shift task priorities: table tennis serves, and Counting Backwards in steps of 7 s. For these self-initiated tasks, dual-task situations will require some kind of strategic scheduling of the component processes, and attentional switching (Abernethy, 1988). Singer (2000) emphasizes that skills can be self-paced (closed) or externally-paced (open), resulting in differences in their information-processing demands. When dealing with self-initiated tasks, we predict that strategy and performance differences between experts and novices become more pronounced. Experts should be more experienced in attentional switching in their sport, and require fewer cognitive resources for planning and executing table-tennis specific actions.

The current study uses two different cognitive tasks: 3-back and Counting Backwards. Both tasks have been used successfully in cognitive-motor dual-task research (Koedijker et al., 2008; Schaefer et al., 2008, 2010, 2015). Three-back requires the continuous updating of working memory (Dobbs & Rule, 1989). In the Counting Backwards task, participants are presented with a 3-digit number, and are asked to count backward in steps of 7. The task requires mental arithmetic skill and working memory (Nairne & Healy, 1983). It is self-paced, since participants decide when to utter the next response.

The two motor tasks from the sport table tennis are returns and serves. For returns, subjects are asked to return balls that are shot by a ball machine, which allows for precisely timed stimuli. For serves, subjects are instructed to serve as many balls as possible throughout the trial. In both cases, they have to hit target fields on the opposing side of the table, always alternating between the left- and right-hand side. The size of the target fields is carefully calibrated to avoid floor or ceiling effects in experts and novices. For both tasks, the score is the number of hits over the course of a trial. In a within-subjects design, both cognitive tasks will be paired with both table tennis tasks, resulting in four task combinations: 3-back and returns (both tasks timed), 3-back and serves (cognition timed, motor task self-initiated), Counting Backwards and returns (cognition self-initiated, motor task timed), and Counting Backwards and serves (both tasks self-initiated).

Subjects will either be novices, or skilled table tennis players who have performed the sport on a competitive level for several years (experts). Given their well-developed skills in table tennis (Rodrigues et al., 2002), we predict that experts will be more accurate and consistent in their movements (Bernstein, 1967; Magill & Anderson, 2014; Schnabel et al., 2007; Williams & Ericsson, 2005). Based on the theories of motor skill learning (Adams, 1971; Gentile, 1972; Fitts & Posner, 1967), and based on the findings by Schaefer and Scornaienchi (2020), we predict that table tennis performances of novices will suffer more from dual-tasking than the performances of experts. For the cognitive tasks, we predict that novices and experts will not differ in their 3-back or Counting Backwards performances under single-task conditions, but novices will show more pronounced performance decrements under dual-task conditions.

Expressing dual-task costs in a percentage metric allows for a comparison of cognitive and motor costs across expertise group or timing-requirements of the task (timed versus self-initiated). We assume that the need to schedule one's responses in self-initiated tasks increases dual-task costs, especially in the condition in which both tasks are self-initiated.

To summarize, the current study wants to replicate and extent the findings of previous expert-novice dual-task studies in the sports domain, by implementing four different task-combinations that differ in the timing-requirements of the component tasks. In addition, the calculation of dual-task costs allows for a systematic comparison of performance decrements across expertise groups and tasks, possible revealing strategy differences between experts and novices.

2. Method

2.1. Sample

2.1.1. Power analysis

Statistical power is increased considerably by assessing performances repeatedly in each subject (Brysbaert, 2019; Brysbaert and Stevens, 2018; Rouder & Haaf, 2018; Zwaan et al., 2018). Our paradigms are based on numerous responses per trial, measured with several trials per condition, for each task. This enables us to assess task reliabilities for each performance domain (3-back scores, correct answers in Counting Backwards, number of hits for serves and returns). Based on the findings by Schaefer and Scornaienchi (2020), we expected the differences between experts and novices in their dual-task decrements to be large. We conducted a Power calculation using the G*3 Power software (Faul et al., 2007), with a significance level of 0.05. The power analysis focused on the interaction effect of expertise group and single- versus dual-task performance decrements. We assumed the correlation among repeated measures to be high ($r = 0.6$), since task reliabilities for table tennis returns and 3-back performances had been very high in previous work with this paradigm (Schaefer & Scornaienchi, 2020). The analysis indicated that a large effect size of $f = 0.4$ would lead to an Actual power of 0.97 with a total sample size of 16 participants. We therefore decided to test 8 participants per group.

2.1.2. Participants

Expert participants were recruited from two local table tennis clubs. All played in the highest or second-highest league of the area (Saarlandliga). This corresponds to the 6th- or 7th-highest league of German table tennis, which consists of 12 leagues. Their mean table tennis experience was 13.94 years ($SD = 2.37$), and all of them competed in table tennis tournaments on a regular basis several times a year. The experts played table tennis for 233 min per week ($SD = 86$) on average. Note that data collection of the current study took place before the Corona pandemic reduced training intensities.

Age-matched novices were contacted by word-of-mouth recruitment among young adults. None of the individuals within the novice group played table tennis as a sport or as a regular leisure time activity. However, they were a physically active group, with regular participation in the following sport activities: fitness center/strength sport ($n = 6$), soccer ($n = 1$), and tennis ($n = 1$). All participants had normal or corrected-to-normal vision and hearing and gave informed consent to the study. As background variable, perceptual-motor speed was measured with the Digit-Symbol Substitution task (Wechsler, 1981). Table 1 shows that the samples did not differ concerning their average age, their overall weekly sports participation, or their Digit Symbol Substitution scores. The Digit Symbol scores corresponded well to young adults' samples of other representative studies (see, for example, Schmiedek et al., 2010). Participants received 30 Euro for their participation in the four sessions of the current study. The study was approved by the Ethics committee of Saarland University.

2.2. Experimental tasks

2.2.1. 3-Back task

The 3-back task is a working memory task with a strong updating component (Dobbs & Rule, 1989). Subjects hear a continuous stream of numbers and are asked to compare the current number to the one 3 positions back in the sequence (for example, the underlined numbers would be targets: 1 4 2 8 <u>4</u> 6 3 7 <u>6</u>…). If subjects recognize a target number, they say “Ja”. The numbers were presented via loudspeakers. The inter-stimulus-interval (ISI) was 2500 ms, since participants had been able to successfully work on ISIs of 2000 and 4000 ms in the study by Schaefer and Scornaienchi (2020). Each trial consisted of 32 stimuli, seven of which were targets and required a “Ja” response. The score consists of the number of hits minus the false alarms (saying “Ja” to a non-target). Each trial lasted for 83 s.

Table 1
Overview of background information on experts and novices.

	Experts	Novices	Significance of *t*-test
N (males/females)	8 (8)	8 (6/2)	
Age (years)			
M	25.0	28.13	n.s.
SD	5.01	12.28	
Weekly sport participation (min)			
M	309	296	n.s.
SD	132	142	
Digit Symbol Substitution test (items)			
M	56.5	49	n.s.
SD	12	11	

2.2.2. Counting Backwards

For the Counting Backwards task, participants receive a 3-digit starting number (e.g., 385), and are asked to count backwards in steps of seven. They name each response, which is scored by the experimenter. The instruction is to name as many correct numbers as possible in each 83-second trial. If participants commit an error, by saying an incorrect number, this response is not included in the score. If successive numbers are correct in relation to the error, they are scored as correct again. Starting numbers do not belong to the series of 7 s.

2.2.3. Table tennis returns

A standard table tennis table (length 274 cm, width 152.5 cm, height 76 cm, net height 15.25 cm) was used. Same as in the study by Schaefer and Scornaienchi (2020), a table tennis robot (Butterfly AMICUS PROFESSIONAL) was positioned at the opposing side of the field. It was attached centrally to the edge of the table (see Fig. 1). The machine presented balls to participants with an ISI of 2500 ms. Balls always arrived at the same spot in the backhand field (15 to 20 cm from the rear edge of the table). Subjects were instructed to return the ball to target fields on the left- and right-hand side of the table, constantly alternating between the two positions, to prevent strategies of “freezing” the degrees of freedom of the motion. The dimensions of the target fields were 40 × 40 cm, and they were positioned 15 cm from the outer bound of the table, 18 cm from the net and 18 cm from the side.

No instructions concerning type of grip (penhold, shakehand) or type of stroke (hit, loop, counter-hip, flip, lob…) were given. One trial consisted of 32 balls, and the reported score was the number of successful hits to the correct target field. Each trial lasted for 83 s. Slow-motion video recordings of the targets fields using the camera of a Samsung Galaxy S8 smartphone accompanied the experimental trials. These recordings enabled the experimenter to re-count the number of hits with high precision after the experimental session.

2.2.4. Table tennis serves

For the serves task, participants were provided with a large number of table tennis balls in a container that was easily accessible from their standing position. They were instructed to serve the balls as quickly and accurately as possible into the target fields, alternating between the left and right-hand side of the field. Each trial lasted for 83 s. The main dependent variable was the number of serves that hit the targets fields. Number of attempts and percentage of hits were also analysed, for exploratory purposes (see Supplementary material 1).

2.3. Procedure

Each participant took part in four experimental sessions, which lasted between 60 and 90 min each. Each session consisted of a combination of one of the two cognitive tasks (3-back, Counting Backwards) with one of the two table tennis tasks (returns, serves). While 3-back and returns are timed, due to the pre-specified time windows in which responses have to be given, Counting Backwards and serves are self-initiated. There were two possible orders of sessions concerning the timing requirements of the task. In the ascending order, participants started in session 1 with both tasks being timed (3-back plus returns). Session 2 assessed 3-back and serves (cognitive task timed, motor task self-initiated), session 3 assessed Counting Backwards and returns

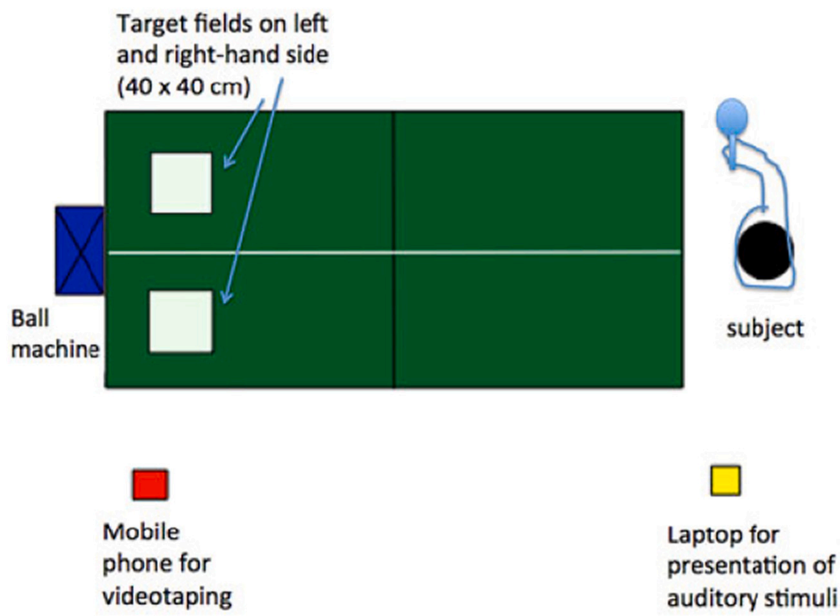

Fig. 1. Experimental setup.
Note. For table tennis returns, 32 balls were presented by a ball machine with an ISI of 2500 ms. For serves, participants had to produce as many serves into the target fields as possible. Trials lasted for 83 s. Participants were instructed to alternate between the right- and left-hand target fields.

(cognitive task self-initiated, motor task timed), and session 4 assessed Counting Backwards and serves (both tasks self-initiated). The descending order administered the sessions in the opposite order, starting with the two self-initiated tasks, and finishing with the two timed tasks. Participants from each group (experts and novices) were equally distributed across the two orders. When 3-back and returns were combined in the dual-task situation, balls and numbers were presented simultaneously.

In session 1, after giving informed consent, participants filled in a questionnaire on demographic information (age, profession) and sports experience. They also completed the Digit Symbol Substitution test. The structure of each session is presented in Table 2. Each session started with table tennis warm-up and the instruction and practice of the respective cognitive task. This phase took several minutes, and performances were not recorded, with the only exception of two practice trials for 3-back. These practice trials are not included in the single-task performance measures. Each session continued with the assessment of single- and dual-task performances. Single- (S) and dual-task trials (D) were distributed across the session in an SDSDS schema, with two trials for each task in every single-task block, and 4 trials in every dual-task block. This design results in 6 single-task trials and 8 dual-task trials per condition, and controls for practice and fatigue effects. Please note that this study design results in 28 trials per task over the course of the study (12 single-task and 16 dual-task trials), because each participant took part in four sessions, with repeated assessments of the four tasks. Participants did not receive feedback about their scores. In the dual-task situations, they were instructed to perform both tasks as well as possible.

Table 2
Procedure for one session.

Condition	Trials
Instruction, practice, warm-up	Table tennis warm up Instruction and practice cognitive task
Single-task block 1	2 trials single-task cognition 2 trials single-task table tennis
Dual-task block 1	4 trials dual-task
Single-task block 2	2 trials single-task cognition 2 trials single-task table tennis
Dual-task block 2	4 trials dual-task
Single-task block 3	2 trials single-task cognition 2 trials single-task table tennis

Note. The table presents an exemplary procedure for one session. All possible combinations of cognitive tasks (3-back, Counting Backwards) and table tennis tasks (returns, serves) were assessed in each participant, resulting in four sessions per participant.

2.4. Analyses

To check for the stability of between-person differences in the dependent measures, Cronbach's Alpha reliabilities are calculated for all task domains, based on the 28 trials that have been assessed over the course of the study. Mixed-design ANOVAs with expertise (2: experts/novices) as between-subjects factor and task conditions (3: single-versus two different dual-task performances) as within-subjects factor are calculated for each dependent measure (3-back, Counting Backwards, table tennis returns, table tennis serves). In addition, dual-task performance decrements are calculated by expressing each individual's performance reductions as a percentage of their single-task performance. These costs are analysed with a mixed-design ANOVA with expertise (2: experts/novices) as between-subjects factor and timing constraints (4: both tasks timed, motor task timed, cognitive task timed, both tasks self-initiated) as within-subjects factors. For the ANOVAs, multivariate F values and partial Eta square values for effect sizes are reported ($\eta^2p > 0.01$ for a small effect, $\eta^2p > 0.06$ for a medium effect, and $\eta^2p > 0.14$ for a large effect), as well as the observed power. If the observed power is below 0.50, the study may have been underpowered to find the specific effect. The alpha level to interpret statistical significance was 0.05. In cases in which sphericity assumptions were violated, Greenhouse-Geisser corrected degrees of freedom and significance levels are reported.

3. Results

3.1. 3-back single- and dual-task performances

Cronbach's Alpha for the 28 trials of the 3-back task was strong ($\alpha = 0.911$), indicating that between-person differences in 3-back performance remain stable over time. Performances were averaged across the trials of the respective condition, resulting in mean scores for the 12 single-task trials, the 8 trials of the dual-task condition with returns, and the 8 trials of the dual-task condition with serves. The upper left hand section of Fig. 2 presents the results of the comparison of single- to dual-task conditions for experts and novices.

The mixed-design ANOVA with expertise group as between-subjects factor and single- versus dual-tasking (3: single, dual with returns, dual with serves) as within-subjects factor revealed a significant main effect of single- versus dual-tasking, F (2, 28) = 10.03, p = .001, $\eta^2 p = 0.417$, *observed power* = 0.974. The interaction of expertise group and single- versus dual-tasking also reached significance, F (2, 28) = 10.60, $p <$ .001, $\eta^2 p = 0.431$, *observed power* = 0.980. In addition, the analysis revealed a significant main effect of expertise group, F (1, 14) = 11.94, p = .004, $\eta^2 p = 0.460$, *observed power* = 0.894.

Performance reductions in the 3-back task induced by playing table tennis were more pronounced in novices as compared to experts. In order to compare the two groups, follow-up independent samples t-tests for the three conditions (single-task, dual-task with returns, dual-task with serves) were conducted, with a Bonferroni correction of the respective significance levels to p = .016. The t-test on single-task performances revealed no expertise differences, t (14) = 0.23, p = .835, *Cohen's d* = 0.11, and the differences between the dual-task condition with returns failed to reach significance by a slight margin, t (14) = 2.60, p = .021, *Cohen's d* = 1.31, due to the Bonferroni correction. The difference between experts and novices in the dual-task condition with serves was significant, t (14) = 7.16, $p <$ .001, *Cohen's d* = 3.59.

3.2. Counting Backwards task, single- and dual-task performances

Cronbach's Alpha for the 28 trials of the Counting Backwards task was excellent (α = 0.995). Performances were averaged across the trials of the respective condition, as described above. The lower left hand section of Fig. 2 presents the results. The mixed-design ANOVA with expertise group as between-subjects factor and single- versus dual-tasking (3: single, dual with returns, dual with serves) as within-subjects factor revealed a significant main effect of single- versus dual-tasking, F (1.25, 17.53) = 6.99, p = .012, $\eta^2 p = 0.333$, *observed power* = 0.763. The interaction of expertise group and single- versus dual-tasking did not reach significance, F (1.25, 17.53) = 1.58, p = .231, $\eta^2 p = 0.101$, *observed power* = 0.240. In addition, the analysis revealed a significant main effect of expertise group, F (1, 14) = 6.07, p = .027, $\eta^2 p$ = 0.303, *observed power* = 0.631.

Performance reductions in the Counting Backwards task induced by playing table tennis were comparable in novices as compared to experts, and experts showed consistently higher performance levels than novices.

3.3. Table tennis returns, single- and dual-task performances

Cronbach's Alpha for the 28 trials of the table tennis returns was excellent (α = 0.986). Results are presented in the upper right hand corner of Fig. 2. Averaged single- and dual-task performances across trials were analysed with a mixed-design ANOVA with expertise group as between-subjects factor and single- versus dual-tasking (3: single, dual with 3-back, dual with Counting Backwards) as within-subjects factor. The main effect of single- versus dual-tasking reached significance, F (2, 28) = 9.13, p = .001, $\eta^2 p = 0.395$, *observed power* = 0.961. There was also a significant interaction of expertise group and single- versus dual-tasking, F (2, 28) = 13.74, $p <$ .001, $\eta^2 p = 0.495$, *observed power* = 0.996. In addition, the analysis revealed a significant main effect of expertise group, F (1, 14) = 15.90, p = .001, $\eta^2 p = 0.532$, *observed power* = 0.959.

In order to compare the two expertise groups, follow-up independent samples t-tests for the three conditions (single-task, dual-task with 3-back, dual-task with Counting Backwards) were conducted. The t-test on returns under single-task conditions failed to reach significance, t (14) = 2.70, p = .021, *Cohen's d* = 1.35, due to the Bonferroni correction of the significance levels to p = .016. However, the differences between experts and novices were significant when returning the balls while performing 3-back, t (14) = 3.45, p = .007, *Cohen's d* = 1.73, and also when returning the balls while counting backwards, t (14) = 4.85, p = .001, *Cohen's d* = 2.43.

3.4. Table tennis serves (hits), single- and dual-task performances

Cronbach's Alpha for the 28 trials of the table tennis serves (number of hits) was excellent (α = 0.996). The average performances for the three conditions are presented in the lower right hand corner of Fig. 2.

The mixed-design ANOVA with expertise group as between-subjects factor and single- versus dual-tasking (3: single, dual with 3-back, dual with Counting Backwards) as within-subjects factor revealed a significant main effect of single- versus dual-tasking, F (1.17, 16.40) = 10.76, p = .003, $\eta^2 p = 0.435$, *observed power* = 0.982. There was no interaction of expertise group and single- versus dual-tasking, F (1.17, 16.40) = 0.31, p = .623, $\eta^2 p = 0.021$, *observed power* = 0.094. The main effect of expertise group was significant, F (1, 14) = 7.27, p = .017, $\eta^2 p = 0.342$, *observed power* = 0.708. Experts consistently outperformed novices, but both groups showed reduced accuracies when concurrently performing a cognitive task.

Using the number of hits as the outcome measure for serves does not take into account that there may be differences in the number of attempts per trial, and also in the percentage of successful serves in relation to the attempts. These additional outcome measures are presented in Supplementary material 1.

In addition, Supplementary material 2 presents analyses of the number of responses given in the following task combinations: both task self-initiated (serves and Counting Backwards) and motor task timed (returns and Counting Backwards). Systematic changes in these parameters give a hint to response scheduling strategies.

3.5. Dual-task costs

For each task condition, dual-task costs (DTCs) were calculated by expressing performance changes under dual-task conditions as a percentage of each individual's single-task performance of the respective task (Somberg & Salthouse, 1982), using the following formula: $\left(\frac{(DT-ST)}{ST}\right) \times (-100)$. Positive values indicate performance reductions under dual-task conditions, while negative values represent superior performance in the dual-task situation. Table 3 shows the DTCs for each individual condition of the current study. Note that the serve-measure was based on the number of hits.

To address the hypothesis that self-initiated tasks lead to an increase in DTCs, DTCs were averaged across the cognitive and the motor domain. Fig. 3 presents the pattern of results. The costs are analysed with a mixed-design ANOVA with expertise (2: experts/novices) as between-subjects factor and timing constraints (4: both tasks timed, motor task timed, cognitive task timed, both tasks self-initiated) as within-subjects factors. The main effect of timing constraints does not reach significance, F (1.3, 18.6) = 0.23, p = .706, $\eta^2 p = 0.016$, *observed power* = 0.089. The interaction of timing constraints and expertise group reached significance, F (1.3, 18.6) = 4.74, p = .034, $\eta^2 p = 0.253$, *observed power* = 0.611. In addition, the analysis revealed a significant main effect of expertise group, F (1, 14) = 30.92, $p <$ .001, $\eta^2 p = 0.688$,

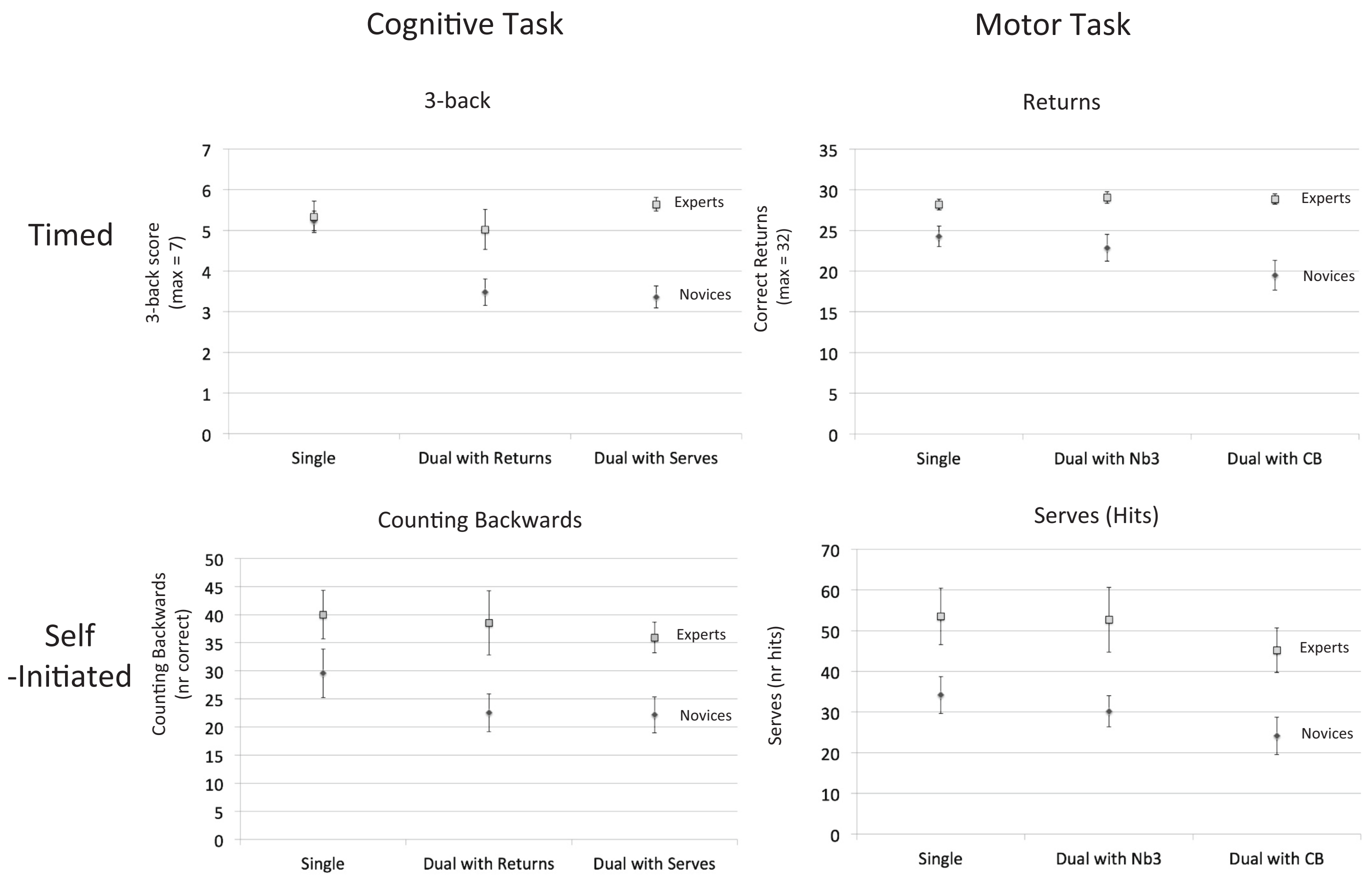

Fig. 2. Single- and dual-task performances in each task combination.
Note. The figures in the left column depict performances in the cognitive tasks, and the figures in the right column depict performances in the motor tasks. The first row of figures depicts the timed tasks, and the second row depicts the self-initiated tasks. Each figure shows the single-task performances and the performances under dual-task conditions. Experts are depicted in light gray, novices in dark gray. Error bars = SE mean.

observed power = 0.999. Averaged across all task-combinations, experts show DTCs of −1.5% (*SD* = 3.7), and novices of 34.6% (*SD* = 18.0). The DTCs of the experts did not differ significantly from zero, $t\,(7) = 1.16$, $p = .284$.

While experts show the predicted increase in DTCs from timed to self-initiated tasks, the pattern is reversed in novices: Their DTCs decrease when the timing constraints of the tasks are relaxed, and their DTCs are lowest when both tasks are self-initiated.[1] To follow-up the interaction of timing constraints and expertise group, repeated-measures ANOVAs were calculated for the four DTCs of each expertise group separately. For the novices, differences between DTCs did not reach significance, $F\,(1.2, 8.4) = 1.81$, $p = .217$, $\eta^2p = 0.206$, *observed power* = 0.236.[2] For experts, the differences between DTCs were significant, $F\,(3, 21) = 7.69$, $p = .001$, $\eta^2p = 0.523$, *observed power* = 0.968. Additional follow-up analyses compared the experts' DTCs of each condition to each other condition, using paired-samples *t*-tests with Bonferroni-corrected levels of significance to $p = .008$. Table 4 presents results of these tests. Only the DTCs of both tasks timed versus both tasks self-initiated differed from each other, with higher costs of the self-initiated task combination. Additional t-tests, for experts only, showed that the DTCs for both tasks timed (*M* = −14; *SD* = 12.5) differed significantly from zero, $t\,(7) = 3.18$, $p = .016$. This was also the case for the DTCs for both tasks self-initiated (*M* = 10.1; *SD* = 3.7), $t\,(7) = 4.5$, $p = .003$. DTCs for both tasks timed were negative, indicating that experts improved their performances compared to the single-task conditions. DTCs for both tasks self-initiated were positive, because performances suffered in the dual-compared to the single-task condition.

4. Discussion

The present study compared table tennis experts and novices in their ability to perform two different table tennis tasks and two different cognitive tasks concurrently. Tasks differed in the extent to which their responses were self-initiated (Counting Backwards, serves), or had to happen in specific time-windows (3-back, returns). For all tasks, performances deteriorated under dual-task conditions, as reflected in a significant main effect of dual-tasking in the respective ANOVAs. In addition, when taking the overall performances for each task into account, experts outperformed novices in every dependent measure, as reflected by the significant main effect of expertise. The predicted interaction of group and single- versus dual-tasking only reached significance for the timed tasks, namely 3-back and returns. This interaction was due to comparable performance levels of experts and novices under single-task conditions, but significant performance differences between the two groups under dual-task conditions. This pattern

[1] The very high standard deviations for the DTCs in the "both tasks timed" condition are caused by an extreme value in the novices, who has DTCs of 187%. If analyses are re-run after excluding this case, the pattern of results remains the same (main effect of timing constraints: $F\,(3, 39) = 0.79$, $p = .506$, $\eta^2p = 0.057$, *observed power* = 0.204; interaction of timing constraints and group: $F\,(3, 39) = 6.17$, $p = .002$, $\eta^2p = 0.322$, *observed power* = 0.944; main effect of group: $F\,(1,13) = 75.3$, $p < .001$, $\eta^2p = 0.853$, *observed power* = 1.0).

[2] The same pattern of findings is obtained when excluding the outlier mentioned in footnote 1. There is no difference between DTCs for the novices, $F\,(3, 18) = 1.31$, $p = .303$, $\eta^2p = 0.179$, *observed power* = 0.289.

Table 3
Dual-task costs (%) by condition in novices and experts.

Time constraints	Task combination	Novices	Experts
Both tasks timed	DTCs 3-back with returns (%)		
	M	33.49	−1.10
	SD	20.48	17.36
	DTCs returns with 3-back (%)		
	M	73.07	−26.88
	SD	115.02	24.17
Cognition self-initiatedMotor task timed	DTCs Counting Backwards with returns (%)		
	M	25.14	5.16
	SD	7.00	6.00
	DTCs returns with counting backward (%)		
	M	47.47	−13.07
	SD	16.97	23.09
Cognition timedMotor task self-initiated	DTCs 3-back with serves (%)		
	M	33.40	−1.53
	SD	17.46	9.70
	DTCs serves with 3-back (%)		
	M	16.53	5.01
	SD	4.49	5.10
Both tasks self-initiated	DTCs Counting Backwards with Serves (%)		
	M	21.02	8.55
	SD	9.74	7.34
	DTCs serves with Counting Backwards (%)		
	M	26.29	11.66
	SD	19.44	9.25

Note. Dual-task costs express performance changes as a percentage of each individual's single-task performance. Positive values represent performance decrements under dual-task conditions, and negative values represent performance improvements.

replicates the findings of Schaefer and Scornaienchi (2020), except that single-task differences between experts and novices in table tennis returns had also reached significance in the previous study.

In the self-initiated tasks of the current study, there are consistent differences between experts and novices, even under single-task conditions. This had been expected for the table tennis task (serves), but not for the cognitive task of Counting Backwards. It can only be speculated why table tennis experts showed superior Counting Backwards performances. The two groups did not differ significantly concerning their cognitive speed, as measured by the Digit Symbol Substitution test (Wechsler, 1981). This test explains variance in several cognitive tasks (Schmiedek et al., 2010). The scores of the experts were a bit higher than those of the novices in the current study (see Table 1), and it is possible that there are additional differences in cognition between the groups. Future research should assess a battery of cognitive tasks to systematically compare experts and novices in this respect. Information on the educational level and professions of the participants would also help to explain such unexpected differences between groups.

The systematic assessment of single- and dual-task performances in all tasks allowed for the calculation of percentage scores for dual-task costs (Somberg & Salthouse, 1982). As predicted, dual-task costs of novices were higher than those of experts. While the overall dual-task costs of experts are close to zero, novices show overall dual-task costs of about 35%, again replicating the results of previous work (Schaefer & Scornaienchi, 2020).

The predicted increase in dual-task costs for self-initiated tasks was only found in the experts, and the effect only reached significance when comparing the DTCs for both tasks timed to the DTCs for both tasks self-initiated. Please note that the DTCs for both tasks timed in the experts were negative, indicating that performances improved under dual-task conditions.

We had predicted the costs for self-initiated tasks to be higher, since the decision to start a response and the constant scheduling of two streams of responses requires cognitive resources. However, one may assume that the need to respond to a task in a specific time-window, which is the requirement for 3-back and table tennis returns, also represents a cognitive challenge, especially when balls und numbers are

Table 4
t-Tests comparing the dual-task costs of different conditions in experts.

Time constraints Task combination 1	Time constraints Task combination 2	*t* (7)	*p*
Both tasks timed	Motor task timed	2.09	.075
Both tasks timed	Cognition timed	2.84	.025
Both tasks timed	Both tasks self-initiated	3.74	**.007**
Motor task timed	Cognition timed	1.02	.343
Motor task timed	Both tasks self-initiated	2.70	.031
Cognition timed	Both tasks self-initiated	3.41	.011

Note. "Both tasks timed" refers to 3-back plus returns, "motor task timed" refers to returns plus Counting Backwards, "cognition timed" refers to 3-back plus serves, and "both tasks self-initiated" refers to Counting Backwards plus serves. *p*-values need to be $< .008$ due to the Bonferroni correction. Significant *p*-values are printed in bold.

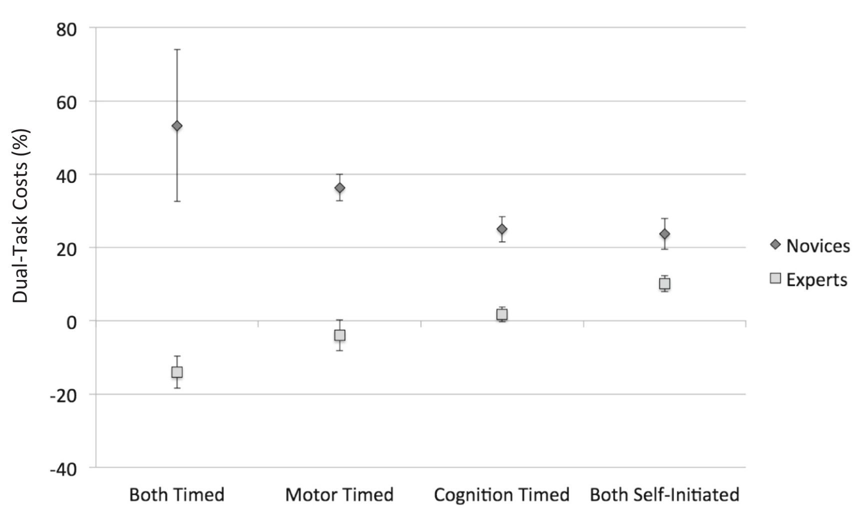

Fig. 3. Dual-task costs (DTCs) by task combination and expertise group.
Note. DTCs were averaged across the motor and cognitive tasks of the respective condition. The order of the conditions "motor timed" and "cognition timed" is freely chosen. Error bars = SE mean.

presented concurrently.[3] The pattern of results for the DTCs of the novices indeed indicates that costs were lower for the self-initiated compared to the timed tasks, although this effect did not reach significance in the current study.

Furthermore, it is possible that the findings are influenced by the properties of the underlying performance measures: The self-initiated tasks of the current study allow for a wide range of performances, and the number of responses/attempts for Counting Backwards and serves in the 83-s trials of the current study shows substantial between-subjects variability (see error bars in Fig. 2, and also Supplement 2). The properties of the timed tasks are different, because there are upper limits to performance (a score of 7 for 3-back, or of 32 hits for returns). In addition, the serves task can be approached by various strategies: Participants can increase or decrease the number of attempts. Fewer attempts with more precision can result in the same outcome (i.e., the same number of correct hits) as more attempts with less precision. We present additional outcome measures for serves (attempts and percentage of successful attempts) in Supplement 1. Interestingly, although both groups reduce the number of attempts when cognitively challenged, experts are able to keep up hitting the target fields with high precision, while there is a clear reduction in the percentage of successful attempts in novices. These findings correspond well to the literature on expert motor skills profiting from divided attention conditions (Beilock, Carr, et al., 2002; Beilock et al., 2004; Wulf et al., 2010). Apparently, although experts perform fewer attempts and also produce fewer hits per trial when cognitively challenged, the proportional accuracy with which they hit the target field remains very high under dual-task conditions (on average between 89 and more than 92%, see Fig. S 1.2 in Supplement 1).

If one task requires reactions in specific time-windows, while the other task is self-paced, it is possible that the timed task leads to a synchronization of task performances. In this way, the timed task will serve as an attractor (Kelso, 1995), leading to a rhythmic performance pattern in the self-initiated task, and reducing the degrees of freedom to strategically influence task priorities in both experts and novices. For example, a participant may adopt a strategy of performing two serves in each time-window of 3-back, or of uttering two numbers of the Counting Backward task in the time-window between two table tennis returns. Such phenomena have been observed in human gait, which tends to synchronize between people under single- and dual-task conditions (Zivotofsky et al., 2012, 2018). Supplement 2 presents the relationship of the number of responses under single- and dual-task conditions for two task combinations involving self-initiated responding. Apparently, there are interindividual differences in the number of responses produced, which may be influenced by the concurrent task. The data recorded for the current study did not allow for a more detailed examination of these tendencies. To address this issue, future research should record and analyse when responses for each task are given. In addition, 3-back performances should be measured in a more continuous manner, by instructing participants to verbalize a response for every target (e.g., by saying "yes" or "no" for each to-be-compared number, or by repeating the previous number). We also realized that participants had a tendency to prolong the verbalization of the next 3-digit-number in the Counting Backwards task (e.g., "three-hundred… um… eh…seventy-six"). This makes it hard to distinguish when the mental calculation actually takes place. The current research paradigm has not been optimized to address specific questions concerning central processing bottlenecks (Pashler, 1994), which may be seen as a limitation. Answers to these questions could be achieved in more controlled laboratory-based environments using highly standardized tasks, while the strength of the current study lays in its' high ecological validity.

Experts in the current study regularly compete in table tennis, with almost 14 years of experience in that sport. Their competitive level is intermediate for the German system. Table tennis poses high demands on visual perception, anticipation, and hand-eye coordination (Bootsma & van Wieringen, 1990; Rodrigues et al., 2002). However, table tennis can also be enjoyed by laypersons and novices, with less ambitious goals. We were able to create two suitable table tennis tasks for a study comparing experts to novices. The chosen size of the target field and the requirement to serve or return balls to the left- and right-hand side of the table kept experts' performances away from the ceiling, and did not create floor effects in the novices. Nevertheless, more fine-grained analyses of motor performances should be employed in future research on table tennis expertise. For example, using a motion tracking system or concentric circles as target fields (Koedijker et al., 2008) would further increase the quality of the data. Including additional groups of table tennis players with even higher performance levels, or with performance levels in-between novices and experts, would also add to our understanding of expertise-related differences in cognitive-motor dual-tasking. Theories on motor skill learning (Adams, 1971; Gentile, 1972; Fitts & Posner, 1967) predict that an intermediate-skilled group shows costs that are in between novices and experts. Note that a study by Amico & Schaefer (same issue) compares intermediate to high-level tennis players. Participants return tennis balls to target fields while concurrently working on 3-back, or while rehearsing to-be-learned word pairs. Results indicate that expertise-related differences in handling a cognitive-motor dual task can be generalized to other sports.

In the recent years, there has been an increasing interest to use cognitive abilities, in particular executive control, to predict performances in dynamic team sports (see Beavan, Chin, et al., 2020, Beavan, Spielmann, et al., 2020; Huijgen et al., 2015, for findings on soccer). We argue that the ability to handle a cognitive-motor dual task in the context of one's sport is a valid predictor of success, over and above performance on "pure" cognitive tasks. Athletes who have additional cognitive resources left when already performing at a high level in the motor task may arrive at superior strategic decisions. For example, an expert soccer player may still be able to pass a ball with high precision to his teammate, even if he is focusing his attention on the positions of several opponents on the field. Shooting precision of a lesser-skilled player may suffer in this situation.

In the current study, participants had not been instructed to prioritize any task. Instead, instruction simply encouraged them to perform the two tasks concurrently "as well as possible". Future research should also investigate whether there are differences between novices and experts in the ability to strategically shift their attention when instructed to do so (see also Li et al., 2005). Differential-emphasis instructions are interesting, since experts may be more flexible in this respect. In competitive situations, athletes who can successfully shield their motor performances from distractions (like anxiety, a large audience, or noise) can outperform their opponents (Mesagno and Beckmann, 2017; for a review, see Furley & Wood, 2016). Recent theories have emphasized that the most successful athletes can adaptively alternate between different modes of bodily awareness, which are automatized or attention-demanding to variable degrees (Furley et al., 2015; Toner & Moran, 2014).

Future studies should also investigate how dual-task performance patterns change with increasing practice when subjects acquire new skills. Studies on the acquisition of table tennis skills have shown distinct improvements in the number of balls landing on target, increased movement consistency (Bootsma et al., 1991) and improved movement stability (Raab et al., 2005). A study by Koedijker et al. (2008) trained participants in a table tennis forehand stroke using four different instructions (explicit, implicit, movement focus, and environment focus learning). Explicit learning, which required the accumulation of a large number of explicit rules, lead to a more pronounced performance decrement when concurrently performing a Counting Backward task (dual-task situation) than the other training regimes. However, changes in task prioritization over the course of training have not been investigated, since single-task performances in cognition were not measured. Future studies should assess dual-tasking repeatedly over the course of

[3] We would like to thank a reviewer for pointing this out to us.

training, including single-task measures for both domains. Dual-task costs are predicted to be reduced over the course of training, because a well-trained motor task requires less attention.

To conclude, the current study was able to replicate and extend the findings of previous cognitive-motor dual-task studies, by showing that novices have higher dual-task costs than experts when performing a table tennis task concurrently to a cognitive task. While experts do not show systematic performance deteriorations, dual-tasking reduces performances of novices by about 35%. Timing-requirements of the tasks influenced the overall dual-task costs of the experts in the expected direction, with increases in dual-task costs when tasks were self-initiated as opposed to timed. We argue that the amount of dual-task costs may be a valid indicator of performance levels for a variety of different sports, potentially over and above performance levels of motor and cognitive skills assessed under single-task conditions.

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Data availability statement

Data to this article will be shared upon request to the corresponding author.

CRediT authorship contribution statement

SS developed the study design. SS and GA contributed equally to the literature overview. SS analysed and interpreted the data with contribution from GA. SS led the writing and draft of the manuscript with support from GA.

Declaration of competing interest

The authors declare no conflict of interest.

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