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The psychophysiological influence of exertion and affect on sport-specific cognitive and physical performance

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ABSTRACT

Objectives: The purpose of the present study was to examine differences in cognitive and physical performance, affective states, perceived exertion, and physiological responses between trials with cognitive, physical, or combined cognitive and physical load.
Design: Randomised cross-over trial.
Methods: Highly trained competitive orienteers (n = 15 men; n = 10 women) completed three randomised trials comprised of: (1) sport-specific cognitive tests; (2) 35-minute cycling time trial; and (3) combined sport-specific cognitive tests and 35-minute cycling time trial. Measures taken during the trials recorded affective states, perceived exertion, heart rate, blood lactate, cycling watts, as well as working memory, updating, planning and decision making.
Results: No significant differences in cognitive performance accuracy were observed within or across trials although reaction times improved within trials and were fastest in the combined trial. Blood lactate, heart rate, perceived exertion, negative affective states, and watts were highest in the physical trial.
Conclusions: The combined load of undertaking sport-specific cognitive tests and a cycling time trial did not influence cognitive performance accuracy. Athletes produced greater watts when completing the physical task independently compared with the combined trial, however psychophysiological responses were worse. Further investigation is warranted to determine whether athletes' attentional focus underpins psychophysiological responses to dual-task sport performance.

Practical implications

- Sport-specific tests of cognitive functioning can be used to more accurately reflect sport performance demands and enhance athletes' training.
- Undertaking sport-specific cognitive and physical tasks at the same time can reduce highly trained orienteers' performance levels in comparison to their performance on the tasks when completed separately.
- Measuring athletes' physiological and perceptual responses to dual-task performance can indicate when athletes' work rate has increased despite limited observable changes in performance outcomes.

1. Introduction

Athletes are required to undertake simultaneous cognitive and physical tasks when competing. Across the duration of a sport event, athletes must endure compounding psychophysiological demands which can influence perceptual and physiological responses that may negatively impact upon performance.[1,2] The cumulative effects of exertion and physiological responses (e.g., blood lactate), derived from the management of physical load athletes contend with during performance, can manifest implications for perceptual-cognitive components of sport performance (e.g., aiming in biathlon).[3,4] However, limited research has investigated how physiological responses, affective states, and exertion may influence cognitive and physical sport performance both independently and simultaneously.[5] The aim of the present study was to explore the differential performance implications of fluctuations in athletes' psychophysiological responses during dual-task execution. Therefore, we assessed variations in orienteering athletes' affective states, perceived exertion, physiological responses, as well as cognitive

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and physical performance across trials with cognitive, physical, or combined cognitive and physical load.

Previous research examining the relationship between athletes' simultaneous cognitive and physical performance highlights the potential influence of dual-task interference, wherein performance decrements are observed in either the cognitive or motor tasks due to psychophysiological demands competing for the athletes' limited resources.[6] Although cognitive dual-task performance has been shown to improve during moderate intensity cycling,[7] dual-task interference is more often observed during high intensity physical load.[8] However, a noted limitation of studies investigating the influence of physical load on cognitive performance has been the predominant use of general cognitive tests measuring executive functioning and inhibition (e.g., Stroop test).[9] The ecological validity of general cognitive tests used in dual-task sport research is somewhat limited[10]; non-sport specific tests do not promote athletes' use of relevant performance strategies they have been developed and implemented within the competition setting.[11] As such, the use of sport-specific tests to replicate competition demands, and more accurately investigate athletes' dual-task performance is warranted.[12]

Athletes participating in orienteering are required to simultaneously undertake dual cognitive and physical tasks whilst managing perceived psychological pressures associated with competition.[13] Orienteers must manage both aerobic and anaerobic components over uneven terrain that also tests agility; simultaneously they are required to plan, make decisions, maintain spatial perception and visuospatial attention, as well as manipulate mental representations associated with working memory.[14] However, research investigating dual-task performance in skilled orienteers has predominantly relied upon general measures of cognition[15] and failed to consider the emotional challenges of sport competition.[16]

Athletes can experience intense affective responses during competition that influence task execution[17]; in particular, elite athletes have been observed to display less affective reactivity under stress and may subsequently preserve resources (via refinement of cortical activity) for effective and efficient cognitive and physical processes underlying sport performance.[18] As such, research examining the differential performance implications of athletes' perceptual and physiological responses during simultaneous dual-task execution would be well served to consider the role of affective responses during competition. Therefore, the purpose of the present study was to examine differences in cognitive and physical performance, affective states, perceived exertion, and physiological responses between trials with cognitive, physical, or combined cognitive and physical load.

2. Methods

Twenty-five highly trained competitive orienteers (15 men, 10 women; mean ± *SD* age = 25.40 ± 6.43 years) were recruited from the elite orienteering centre based at a post-secondary institution in Sweden (n = 17) in addition to high level competitive orienteers living local to the area (n = 8). Participants' primary competitive orienteering discipline included running (n = 13) and ski-orienteering (n = 12); they reported their current level of competition (9 international, 13 national, 3 regional), and their highest level of competition (15 international, 9 national, 1 regional). The participants currently trained between 4 and 15 (M = 8.29, *SD* = 3.05) h per week. Their mean height and weight were 177.84 (*SD* = 8.79) cm and 70.85 (*SD* = 6.90) kg respectively.

Ethical approval for the study was provided by the Swedish Ethical Review Authority Regional Ethics board (Dnr: 2019-01052). Participants received information about the protocol and provided written consent prior to undertaking the study. Participants were informed to refrain from strenuous physical activity for 24 h prior to each trial.

A randomised cross-over research design required participants to undertake three trials (i.e., cognitive, physical, combined) with one week between each trial (please see Supplementary material for a schematic of the protocol). During completion of each of the trials the participants sat on an SRM ergometer bike for the duration and no performance feedback was provided. The participants were informed that the study was a competition, and the athlete recording the best combined performance on the physical and cognitive tests would win a prize valued at 1000 SEK (approximately €100). In completion of the physical and combined trials participants were told to cycle the greatest distance possible in a time of 35 min; participants were informed their reaction time and accuracy that were recorded as performance measures on all cognitive tests.

Participants' affective valence was measured by the Feeling Scale (FS)[19] with a 11-point bipolar measurement scale of pleasure–displeasure, ranging from +5 (*I feel very good*) to −5 (*I feel very bad*). Whole-body ratings of perceived exertion were recorded using the Rating of Perceived Exertion scale (RPE).[20] Participants stated the number that reflected how difficult the exercise felt on a 6–20 scale, ranging from 6 (*no exertion at all*) through 13 (*somewhat hard*) to 20 (*maximal exertion*). In line with recommendations,[20] participants were provided standardised instruction on how to use the scale and confirmed that they had used it previously.

Physiological responses were calculated via heart rate (HR, bpm) continuously measured (Polar H7; Polar Electro Oy, Kuopio Finland) during the trials. Additionally, blood lactate concentrations (BL) were assessed using blood samples (25 μL) collected from the finger and analysed immediately (BIOSEN C_Line Clinic 2; FYSIOTEST, Båstad Sweden).

Physical performance measures were recorded in the form of continuous power output (PO, W) on an SRM cycle ergometer (Schoberer Rad Meßtechnik SRM GmbH, Jülich, Germany). Cognitive performance was recorded using three sport-specific tests measuring a range of cognitive functions (i.e., working memory, updating, planning and decision making) to emulate the cognitive demands of orienteering competition. Specifically, the "Route Choice" test aimed to measure the ability to plan and make quick and correct judgements regarding the shortest of three route choices on an orienteering map. The test was specifically developed for this study to increase the ecological validity for the sport of orienteering (please see Supplementary material for explanation of development and examples of cognitive tests). Five route choice tasks were included in each of five test blocks. The Matrix Monitoring test was used to measure the ability to update information[21] and is relevant in the implementation of a planned route in orienteering. Five trials of the test were included in each test block. A modified visual n-back test[22] using map symbols measured the process of updating within working memory, which is relevant in an orienteering context where the athletes constantly have to update their memory regarding which objects they plan to encounter between controls. Twenty trials of the test were completed in each test block. All cognitive tests were presented on a screen connected to a computer using the software package E-prime (Psychology Software Tools, Pittsburgh, PA). Participants used a standard keyboard within arm's reach and relevant keys for responding were colour coded or labelled "Yes" and "No".

Prior to completing the cognitive and combined trials, participants undertook short practice tests for each of the cognitive tests; before commencing the physical and combined trials participants were provided 5 min to warm up at a self-selected cycling pace. Immediately before the trial commenced, participants reported their current affective state (FS), perceived exertion (RPE), and had their HR as well as BL measured. The participants were told to start cycling when ready; after 2 min of cycling the first of five blocks of cognitive tests was presented (i.e., 2, 8, 14, 20, 26 min). Each block was comprised of the three tests presented every 2 min (i.e., 1 min of cognitive test, followed by 1 min of cycling). The order of the cognitive tests was the same in all the blocks (i.e., Route Choice, Matrix Monitoring, Symbol-2-back). When the last cognitive test in each block was completed RPE, FS, HR, BL were recorded (i.e., 7, 13, 19, 25, 31 min). After the last block of cognitive tests and psychophysiological measures were taken (i.e., 32) participants cycled until the time trial finished at 35 and RPE, FS, HR, BL were recorded once more. The testing procedure and timing of the psychophysiological measures (i.e., RPE, FS, HR, BL) were the same for both the cognitive trial except no cycling was undertaken, and the physical trial in which only the 35-minute cycling time trial was completed.

JASP version 0.15 was used for the statistical analyses. First, dependent samples *t*-tests were conducted to examine differences in physical performance between the physical and combined trials. We used two-way repeated measures ANOVA and post hoc comparisons to examine differences within and between the trials in cognitive performance, feeling states, perceived exertion, and physiological responses. The repeated measures analyses only included data collected during trials. Thus, data on feeling states, perceived exertion, and physiological responses collected immediately before each trial commenced were excluded from these analyses. Greenhouse–Geiser corrections were applied if the assumption of sphericity was violated and *p* values were adjusted for multiple comparisons using the Holm method. The significance level was set to .05 in all analyses.

3. Results

Dependent samples *t*-tests showed statistically significant differences between the trials in watts ($p = .018$, Cohen's $d = 0.532$, 95% CI [0.089, 0.964], $n = 24$). The participants achieved a lower power output in the combined trial ($M_{watt} = 172.55$, $SD = 29.65$) compared to the physical trial ($M_{watt} = 183.07$, $SD = 32.84$).

Regarding cognitive performance (see Fig. 1), no statistically significant main effect of trial ($F = 2.813$, $df = 1, 23$, $p = .107$, $\omega^2 = 0.027$), repeated measures ($F = 6.317$, $df = 4, 92$, $p = .066$, $\omega^2 = 0.033$) or interaction effect ($F = 0.815$, $df = 4, 92$, $p = .519$, $\omega^2 = 0.000$) was observed for the matrix monitoring test. Neither was a statistically significant main effect of trial ($F = 2.722$, $df = 1, 23$, $p = .113$, $\omega^2 = 0.020$), repeated measures ($F = 0.762$, $df = 4, 92$, $p = .553$, $\omega^2 = 0.000$) or interaction effect ($F = 0.255$, $df = 4, 92$, $p = .906$, $\omega^2 = 0.000$) observed for accuracy on the route choice test. With regard to reaction time on the route choice test, we observed a significant main effect of trial ($F = 6.823$, $df = 1, 23$, $p = .016$, $\omega^2 = 0.038$) and repeated measures ($F = 4.256$, $df = 2.627, 60.431$, $p = .011$, $\omega^2 = 0.012$). However, the interaction between trial and repeated measures was not statistically significant ($F = 0.502$, $df = 4, 92$, $p = .734$, $\omega^2 = 0.000$). We did not observe a statistically significant main effect of trial ($F = 0.440$, $df = 1, 23$, $p = .514$, $\omega^2 = 0.000$), repeated measures ($F = 2.368$, $df = 2.228, 51.251$, $p = .098$, $\omega^2 = 0.025$), or interaction effect ($F = 0.130$, $df = 4, 92$, $p = .971$, $\omega^2 = 0.000$) regarding accuracy on the symbol-2-back test. With regard to reaction time on the symbol-2-back test we observed a significant main effect for trial ($F = 7.705$, $df = 1, 23$, $p = .011$, $\omega^2 = 0.061$) and repeated measures ($F = 5.552$, $df = 4, 92$, $p < .001$, $\omega^2 = 0.026$). However, the interaction between trial and repeated measures was not statistically significant ($F = 0.634$, $df = 4, 92$, $p = .639$, $\omega^2 = 0.000$).

There was a statistically significant main effect of trial ($F = 23.299$, $df = 2, 44$, $p < .001$, $\omega^2 = 0.239$), repeated measures ($F = 39.889$, $df = 2.072, 45.547$, $p < .001$, $\omega^2 = 0.224$), and a statistically significant interaction between trial and repeated measures ($F = 18.176$, $df = 3.995, 87.900$, $p < .001$, $\omega^2 = 0.131$) for feeling states (Fig. 2). Post hoc comparisons indicated increasing and statistically significant differences between the physical and cognitive trials from T3 (minute 19) and onwards, whereas increasing and statistically significant differences between the combined trial and cognitive trial were found at T4 (minute 25) and onwards. On average, the participants reported less pleasant feeling states during the physical trial compared to the cognitive ($\Delta M = -2.181$, $p < .001$, Cohen's $d = -1.522$) or combined trial ($\Delta M = -0.775$, $p = .011$,

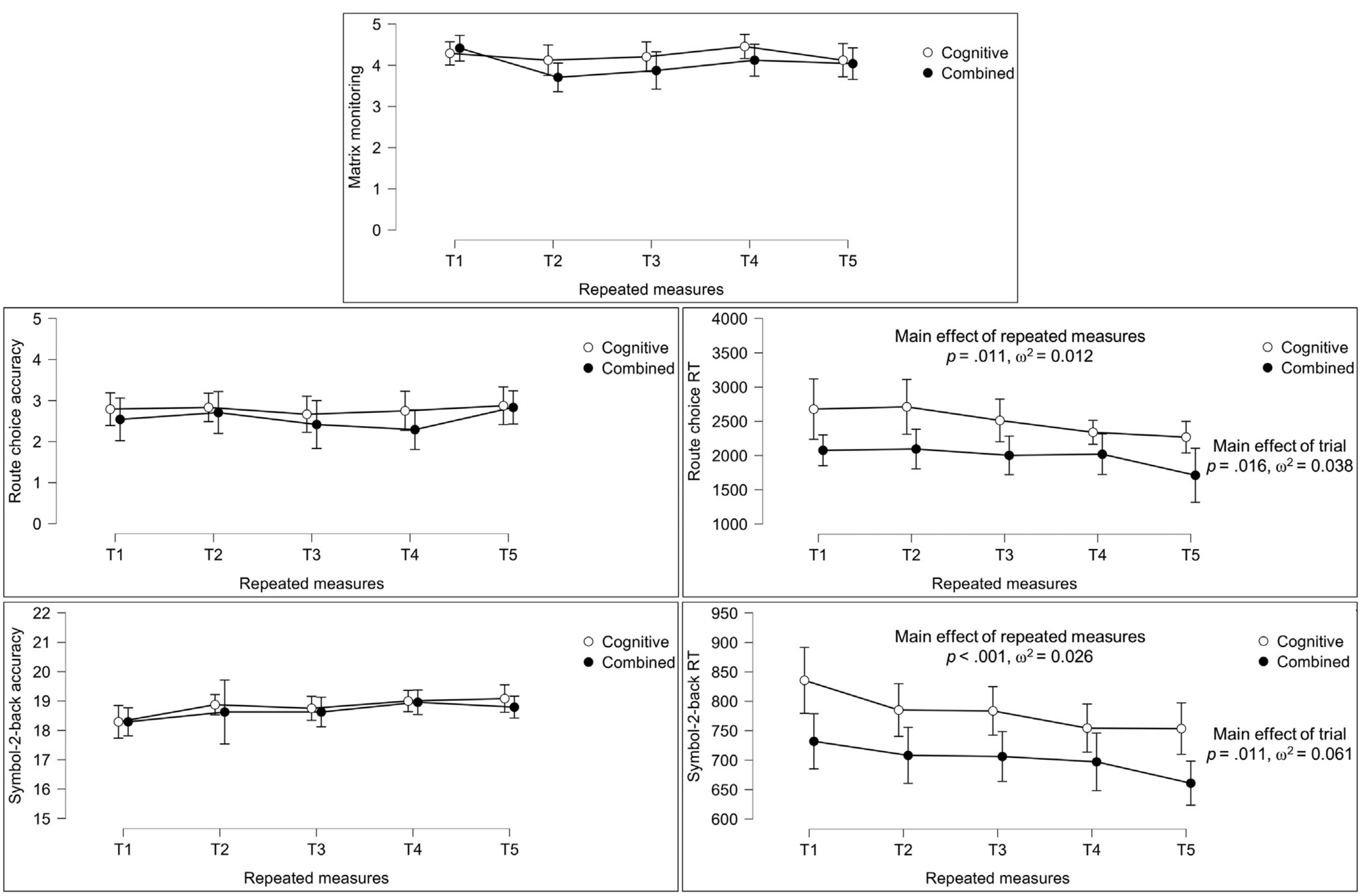
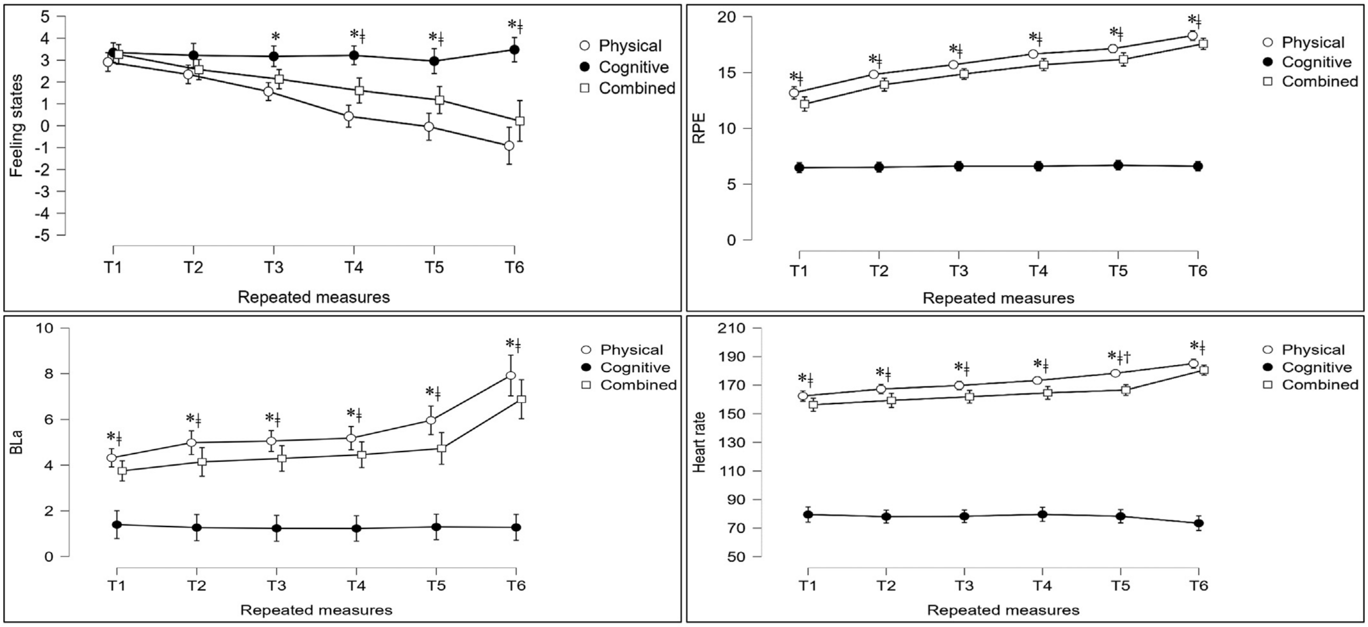


Fig. 1. Accuracy and reaction time during cognitive performance across cognitive and combined trials.



Note.
* indicates statistically significant difference ($p < .05$) between the physical and cognitive trial.
‡ indicates statistically significant difference ($p < .05$) between the combined and cognitive trial.
† indicates statistically significant difference ($p < .05$) between the physical and combined trial.

Fig. 2. Affect, perceived exertion, blood lactate, and heart rate across physical, cognitive, and combined trials.

Cohen's $d = -0.580$), and more pleasant feeling states during the cognitive trial than the combined trial ($\Delta M = 1.406$, $p = .003$, Cohen's $d = 0.763$).

There was a statistically significant main effect of trial ($F = 638.732$, $df = 1.213$, 26.675, $p < .001$, $\omega^2 = 0.923$), repeated measures ($F = 170.743$, $df = 2.196$, 48.316, $p < .001$, $\omega^2 = 0.559$), and a statistically significant interaction between trial and repeated measures ($F = 59.246$, $df = 4.293$, 94.437, $p < .001$, $\omega^2 = 0.350$) for perceived exertion (Fig. 2). Post hoc comparisons indicated increasing and statistically significant differences between the physical and combined trials and the cognitive trial from T1 (minute 7) and onwards. On average, the participants reported higher perceived exertion in the physical trial compared to the cognitive ($\Delta M = 9.377$, $p < .001$, Cohen's $d = 9.092$) and combined trial ($\Delta M = 0.899$, $p < .001$, Cohen's $d = 0.806$), and lower perceived exertion in the cognitive trial than the combined trial ($\Delta M = -8.478$, $p < .001$, Cohen's $d = -4.546$).

There was a statistically significant main effect of trial ($F = 62.269$, $df = 2, 42$, $p < .001$, $\omega^2 = 0.544$), repeated measures ($F = 50.390$, $df = 1.765$, 37.062, $p < .001$, $\omega^2 = 0.215$), and a statistically significant interaction between trial and repeated measures ($F = 20.816$, $df = 3.725$, 78.255, $p < .001$, $\omega^2 = 0.121$) for BL (Fig. 2). Post hoc comparisons indicated increasing and statistically significant differences between the physical and combined trials and cognitive trial from T1 (minute 7) and onwards. Comparisons between the trials indicated higher BL in the physical trial compared to the cognitive ($\Delta M = 4.288$, $p < .001$, Cohen's $d = 2.292$) and combined trial ($\Delta M = 0.861$, $p = .023$, Cohen's $d = 0.522$). They also had higher BL in the combined than the cognitive trial ($\Delta M = 3.428$, $p < .001$, Cohen's $d = 1.583$).

There was a statistically significant main effect of trial ($F = 649.684$, $df = 1.465$, 30.774, $p < .001$, $\omega^2 = 0.921$), repeated measures ($F = 65.444$, $df = 2.657$, 55.789, $p < .001$, $\omega^2 = 0.158$), and a statistically significant interaction between trial and repeated measures ($F = 38.216$, $df = 4.910$, 103.101, $p < .001$, $\omega^2 = 0.153$) for HR (Fig. 2). Post hoc comparisons indicated increasing and statistically significant differences between the physical and combined trials and cognitive trial from T1 (minute 7) and onwards. A statistically significant difference between the physical and combined trials was found at T5 (minute 31). Comparisons between the trials indicated higher HR in the physical trial compared to the cognitive ($\Delta M = 94.848$, $p < .001$, Cohen's $d = 7.141$) and the combined trial ($\Delta M = 7.788$, $p = .001$, Cohen's $d = 0.796$), and higher HR in the combined than cognitive trial ($\Delta M = 87.061$, $p < .001$, Cohen's $d = 5.102$).

4. Discussion

The present study examined differences in cognitive and physical performance, affective states, perceived exertion, and physiological responses between trials with cognitive, physical, or combined cognitive and physical load. The main finding of the present study is that in the combined trial participants' accuracy on the cognitive tasks did not suffer performance decrements, however physical performance (i.e., watts) was significantly worse than in the physical trial.

In line with the higher power output recorded in the physical trial, the orienteers' physiological and perceptual responses were significantly worse (i.e., higher HR, BL, exertion; lower affect) in comparison with completion of the combined trial with simultaneous cognitive and physical load. The increased power output during the physical trial can be linked with the increased physiological expenditure as well as the observed degradation of perceptual and physiological responses. It is worth noting that athletes' time trial performance and pacing can be influenced by their affective state and attentional focus.[23] During the completion of a cycling time trial, wherein a high workload over a prolonged duration is required, physiological sensations are overwhelmingly salient and an associative attention focus is virtually unavoidable.[24] An internal attentional focus on core components of cycling and pacing has been linked with optimal performance[25]; however, during the combined trial participants were required to focus on the external task of completing the cognitive tests, which may have diverted attention from cycling and subsequently reduced power output. Previous research highlights attentional focus can augment perceptual (e.g., exertion, affect) as well as physiological responses (e.g., oxygen consumption, blood lactate) and ultimately impact upon perfomance.[25,26] Future research examining dual-task performance would benefit from using study designs that extend the duration of the protocol to induce a severely fatigued state (e.g., time to exhaustion)[27] and use psychophysiological measures that can examine the implications of attentional focus, affect, and exertion (e.g., EEG).[28]

In terms of cognitive performance in the present study, participants' accuracy on the sport-specific cognitive tests did not differ between trials; however, their reaction times were significantly quicker in the combined trial. Future studies comprised of research designs with randomised trials may attempt to differentiate whether the faster reaction times were promoted via independent changes in physiological activation or affective states and delineate performance variation derived from the interaction of co-occurring changes.[29] In terms of applied implications, it warrants noting that orienteers' performance outcomes/competition results can be enhanced by making quick decisions that result in faster course completion.[13] Previous research highlights athletes can improve sport performance by undertaking training protocols targeting cognitive functions (e.g., decision making speed and accuracy); however, to enhance performance outcomes in competition settings, sport-specific cognitive tasks using an ecological approach to skill development is optimal.[30]

This study has limitations that warrant consideration for future research examining the influence of athletes' psychophysiological responses on sport performance during competition. To differentiate the influence of key variables the data collection in this study was completed in a laboratory; these findings may be augmented by environmental factors comprising the sporting arena that influence physiological responses and performance during competition, and future studies should be undertaken in the field to increase ecological validity.[12,30] On a related note, the physical task in the present study was a cycling time trial; although the athletes in the present study reported cycling as a common training method, and the use of a cycling ergometer facilitated a safer and more efficient data collection on the cognitive tests, it is acknowledged that running or cross-country skiing would have more closely replicated the physical performance demands of competitions. The sport-specific cognitive tests used in the present study were designed to emulate competition demands, as well as advance understanding of the link between athletes' psychophysiological responses and dual-task performance outcomes. Future studies with an increased sample size may seek to further validate the tests and examine if performance can be predicted by the psychophysiological variables measured in the present study using alternative approaches to data analysis (e.g., regression).

5. Conclusion

The present study highlights the importance of delimiting psychophysiological variables underlying the completion of dual-task sport performance to identify implications for performance outcomes. Further, the findings indicate the potential of sport-specific cognitive tasks for use in testing athletes' responses to dual-task performance demands. Future studies undertaken at competition events may extend the findings of this study and assist in the development of interventions to optimise athletes' psychophysiological responses to maximise sport performance.

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Declaration of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Confirmation of ethical compliance

All research procedures were in accordance with the ethical standards of the Swedish Ethical Review Authority, the 1964 Helsinki Declaration and its later amendments. Ethical approval was confirmed by Swedish Ethical Review Authority Regional Ethics board based at Umeå University (Dnr: 2019-01052). All athletes provided informed consent for use of their data for research purposes. All data were anonymised.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2022.05.008.

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