Cognitive-motor multitasking in athletes with and without intellectual impairment

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This article has been accepted for publication and undergone peer review but has not been through copyediting, typesetting, pagination and proofreading, which may lead to differences between this version and the published version. The final published version can be accessed at and cited as: doi:10.1111/sms.14088. Use of this article for non-commercial purposes is in compliance with the Wiley Self-Archiving Policy.

ABSTRACT

Purpose. We investigated cognitive-motor multitasking in 29 top-athletes with intellectual impairment (II) recruited during the European Championship Games organized by Virtus (World Intellectual Impairment Sports) and 29 control (CT) athletes matched for age, sex, sports practiced and lifetime accumulated practice hours. ***Methods***. Participants performed a cognitive task that required recognizing previously displayed visual objects among distractors. The motor task required maintaining a stable upright posture balancing on a rocking board placed atop a force plate which assessed center-of-pressure (COP) movement. Both tasks were performed separately (with participants seated for the cognitive single-task) and concurrently under dual-task conditions, wherein participants memorized objects while balancing. We analyzed recognition accuracy, COP path length and sample entropy of the COP trajectory as a measure for automaticity of postural control. ***Results***. As expected, CT-athletes outperformed II-athletes in the cognitive task but the two groups have comparable performance in the postural task under single- and dual-task conditions. When multitasking, CT-athletes switched to more automatic postural control and maintained their postural sway at single-task levels. II-athletes prioritized balance thereby successfully keeping COP excursion comparable to single-task conditions. However, this came with pronounced costs for memory performance, which was unaffected by multitasking in CT-athletes. ***Conclusion***. The adaptive capacity observed in control athletes was not at the disposal of II-athletes who revealed pronounced sensitivities to multitasking interference. This sensitivity obviously was not compensated for by either athletic competence or potential transfer of athletic skill to domain-general cognitive functions.

Keywords: center-of-pressure; disability sport; dual-task; postural control; sample entropy; task interference

1. INTRODUCTION

While the role of neuromusculoskeletal functions (e.g., strength, power, and endurance) in sports performance has been well acknowledged in the sports literature, the contribution of cognition to elite sports performance has often been underappreciated and received less attention from researchers. Voss et al.[1] described two approaches to studying the performance–cognition relationship. The *expert performance approach* views elite athletes' advantage as domain-specific with little to no transfer beyond their domain of expertise. A meta-analysis by Mann et al.[2] indeed revealed higher performances in elite athletes compared with novices for cognitive and perceptual abilities to be limited to ecologically valid tasks that simulate contexts specific to athletes' sports. In contrast, the *cognitive component skills approach* assumes that athletes have superior domain-general cognitive capacities due to the intrinsic cognitive demands of their sport. A critical assumption of this approach is that athletes are able to demonstrate these advantages outside sport-specific contexts. This assumption is supported by studies reporting domain-general advantages of elite athletes over novices in cognitive abilities like processing speed, working memory, and cognitive control.[1,3,4] There is, however, a lack of clarity whether elite athletes' advantageous cognitive skills arise from training or selection effects (i.e., individuals with better innate cognitive abilities are more likely to persist in training and succeed to elite levels).[1] For instance, there is evidence that domain-general cognitive control skills are correlated with prospective success in sports like tennis[5] and soccer.[6]

Studying the impact of intellectual impairment (II) on sport performance has the potential to forward our understanding of the role that cognition plays in elite sports performance and its development. World records from II-sports and mainstream sports clearly indicate a discrepancy in athletic standards between II- and non-II-athletes, with the former underperforming compared to the latter.[7] The disadvantage of II-athletes in sports performance appeared to be greater in more technical and cognitively demanding sport events.[7] One interpretation of such findings is that II constrains the cognitive functions necessary to push athletic performance to the highest levels.

However, because intelligence (based on IQ scores) by itself does not correlate with tactical and technical proficiency in sports, it is still unclear how cognition affects expert sport performance (see Burns[8]).

The cognitive-motor dual-task (DT) paradigm is a promising approach to clarify the relationship between II and sport performance. In this paradigm, participants concurrently execute a cognitive and a motor task, which can result in performance on one or both tasks to deteriorate compared with performance levels during separate execution.[9] Resource theories postulate that performance decrements occur if the resource demands of the tasks performed simultaneously exceed the limited resource available.[10] If performance deteriorates under DT conditions, individuals often prioritize one task over the other, a tendency determined by several factors such as functional capacity and anticipated hazard.[11] In the case of cognition-posture DT, the process of task prioritization favors the postural task over the cognitive task, particularly in older adults and individuals with postural impairment (who possess low postural reserves) or when faced with difficult or novel postural tasks (which have high anticipated hazards).[11,12]

The use of the DT paradigm to evaluate the constraining effect of II on sport performance is sensible for at least three reasons. First, DT performance is crucial in many sports, like dribbling a ball while mentally tracking positions of teammates and/or opponents in basketball or football. As the closest paradigm that replicates the concurrent processing of multiple tasks typical in many sport contexts,[13] it is a more ecologically valid approach to better understand the cognition-sport performance relationship. Second, evidence suggests that II-athletes have heightened susceptibility to DT effects, which may be attributed to their smaller cognitive resource pool due to impairment. Several studies observed greater performance decline in DT situations in II-children[14,15] as well as II-adults[16,17] compared to their non-II-counterparts. In contrast, greater resistance to DT effects have been demonstrated for elite athletes from various sports like athletics,[3] gymnastics,[18] and table tennis.[19] Lastly, the use of DT paradigm on II-athletes could uncover cognitive benefits of sports participation considering the positive influence of athletic expertise on DT performance. Beyond benefits in domain-specific DT ability, several studies have provided evidence that athletes' superior DT ability may transfer to non-sport situations.[3,9,18] For instance, in a DT experiment using virtual reality street crossing while conversing on a mobile phone, Chaddock and colleagues[3] reported that athletes had better crossing success rates and fewer collisions than non-athletes.

Motor learning theorists equated skill acquisition and expert performance with decreasing cognitive resource investment for task execution as the result of automatization.[20,21,22] In line with this assumption, studies found higher center-of-pressure (COP) entropy scores in expert dancers' postural control compared with novices.[23] Entropy measures can be used to quantify the irregularity of COP trajectories. This COP parameter is considered to reflect the degree of automaticity in postural control for upright stance. Accordingly, higher entropy or more irregular COP trajectories indicate a higher degree of automaticity or that smaller amounts of cognitive resources need to be devoted to the task.[24,25] In contrast, individuals of advancing ages and pathologies tended to prioritize postural task, especially in difficult task situations, presumably as a compensatory strategy for impaired sensorimotor processing resulting from age or impairment.[12] This strategic increase in cognitive resource allocation to postural control is reflected in more regular COP trajectories or lower entropy scores observed in the elderly[26] and individuals with Down syndrome.[27] As a COP parameter, entropy measures also have the advantage that they might be more sensitive to age-, training-, and impairment-related effects that would otherwise be undetected by traditional COP parameters.[28,29]

Despite the potential of DT paradigm to uncover cognition-sport performance relationship, there is paucity of research on this subject. To our knowledge only a single study has been published on II-athletes' DT capacity and it indeed found that II-athletes had larger DT performance decrements (i.e., DT cost [DTC]) than non-II-athletes.[17] Postural tasks performed in single-task (ST) and DT conditions, however, were not identical, which limits comparability. Moreover, the authors used total time of single-leg standing to quantify postural stability, which may reflect the outcome of postural control but does not characterize the underlying processes, particularly as far as automaticity is concerned.

The current study had three objectives. First, we examined ST and DT performance in a cognitive and postural task and hypothesized that II-athletes would have: a) worse postural (i.e., longer path lengths) and cognitive (i.e., worse accuracy) performance; b) more regular COP trajectories (i.e., smaller entropies pointing to reduced automatization similar to older adults and individuals with neurocognitive impairment); and c) larger DTCs in both postural and cognitive tasks. Second, we investigated adaptive response of II-athletes to a multitasking situation. From previous studies with older participants and individuals with psychopathological conditions, we hypothesized a higher need for II-athletes to protect their posture at the cost of the cognitive task (i.e., prioritization) under DT conditions. Considering that prioritization implies that individuals allocate more attentional resources to a certain task when facing multitasking challenges, we also expected group differences in postural control automaticity (i.e., irregularity of COP trajectories) to be pronounced in DT contexts. Lastly, as an exploratory analysis, we examined the relations between measures of postural stability (i.e., COP path length) and entropy in ST and DT contexts. Our reasoning was that if CT-athletes were capable of tuning the degree of automaticity in their postural control, entropy should be correlated with stability in this group more so than in II-athletes. Assuming further that this fine-tuning represents a successful adaptation, correlations (and differences between groups therein) should be highest in DT condition.

2. METHODS

2.1 Participants

For an *a priori* power analysis, we focused on impairment group x task context (ST versus DT performance) interaction and expected the size of interaction effects to be between small and medium based on an earlier DT study with II-athletes.[17] Power calculation conducted using

G*Power[30] indicated that a total of 58 participants was needed to detect an effect size $f = 0.19$, with 80% power, $\alpha = 0.05$, and correlation among repeated measures to be $r = 0.50$.

Recruitment and testing of 29 II-athletes were conducted during the 2018 European Championship Games organized by Virtus (formerly INAS or International Federation for Athletes with Intellectual Impairments). II-athletes practiced one of the six sports (i.e., athletics, basketball, cycling, swimming, table tennis, and tennis) and they all met the diagnostic criteria for mild to moderate II.[31] Exclusion criteria includes: 1) use of psychotropic medications; 2) need for mobility aids to stand or ambulate; 3); have visual acuity < 0.3 logMAR; 4) musculoskeletal injury within the last 12 months; and 5) declared diagnosis of genetic disorders like Down syndrome. We retrieved II-athletes' intelligence quotient scores (based on Wechsler Intelligence Scale for Children or Wechsler Adult Intelligence Scale) from Virtus' database. Training history (e.g., years of training and hours of training per week) were obtained from self-reports of II-athletes that were confirmed by their respective coaches. A control sample of athletes (CT-athletes), matched by age, sex, sport practiced, and lifetime accumulated training hours, was thereafter recruited from and tested in Belgium. Table 1 shows summary statistics for sample characteristics. All participants provided a written informed consent prior to participation. Ethical approval for this study was granted by the UZ/KU Leuven Research Ethics Committee (B322201731833/S59931).

*< insert **Table 1** here >*

2.2 Tasks and procedure

The cognitive task was a Recognition Task involving a series of 20 photographs of common objects like apple, comb, horse and train (200 objects in total with no objects repeated within and between trials) laid against a white background, which appeared one at a time on the screen at a frequency of 0.67 Hz. Stimulus presentation time was 0.5 s, after which only the white background remained until the next photograph appeared. At the start of every trial, a 5-cm fixation circle on a white background stayed on screen for 3 seconds before disappearing. Two seconds thereafter, the first image appeared. At the end of the trial, we showed a display with 12 images (i.e., five target items and seven distractors) and asked the participants to point to five objects that appeared on the screen. Participants performed this task while seated during ST cognition (STc) trials and standing during DT trials.

For the postural task, we recorded COP excursion as participants stood for 35 seconds on a 450 x 450 x 53 mm rocking board (maximum 20° forward and 20° backward tilt) that was laid atop a 502 x 502 x 45.5 mm force plate (AccuSway, Advanced Mechanical Technology Inc., Watertown, MA). To keep foot placement consistent across trials, foot outlines were drawn while participants stood at hip-width apart with big toes pointing forward and medial malleoli aligned with the rocking board's rotation axis. A 5-cm black fixation circle on a white background was displayed on an 89-cm screen that hang on the wall 2 m away at eye level. Two assistants stood ready (behind but outside participant's peripheral vision) during standing trials for support in case of falls.

Postural and cognitive tasks were performed separately in the ST condition and concurrently in the DT condition, yielding three experimental conditions: ST cognition (STc), ST posture (STp), and DT. In the STc condition, we instructed the participants to "try to remember as many objects as you can." For STp trials, participants were asked to "stand as steady as possible with your arms at your side and look straight ahead at the black circle." Instructions for the DT trials were to "stand as steady as possible with your arms at your side while you remember as many objects as you can." We emphasized the equal importance of both tasks and reminded participants that they should perform them equally well. This is to avoid imposing prioritization of one task over the other. Except during practice trials, no feedback on performance was given to avoid participants strategizing based on knowledge of their performance. The STp and DT conditions were performed in two test blocks. The STc condition was done in three blocks. Each block consisted of two trials. Testing order, which was the same for all participants, was: STc – STp – DT – STc – DT – STp – STc. All participants performed two successful practice trials of the postural and cognitive tasks prior to testing for familiarization. To obtain IQ estimates for CT-athletes, we administered an index-based abbreviation of Wechsler Adult Intelligence Scale III (Dutch version) comprised of four subscales, namely vocabulary, digit span, matrix reasoning and symbol substitution at the end of testing.

2.3 Data reduction and statistical analysis

Performance accuracy in the cognitive task was computed based on proportion of correct response (expressed as a percentage), which is equal to the sum of the number of hits (i.e., pointing to an image that appeared on the screen) and the number of correct rejections (i.e., not pointing to an image that did not appear on the screen) divided by 12. This formula places equal importance on selecting targets and ignoring distractors, particularly relevant to the current study where there was uneven number of targets and distractors.[32] COP data were acquired at a sampling frequency of 100 Hz and was filtered using a fourth-order zero-phase Butterworth low-pass filter with a cut-off frequency of 10 Hz.[33,34] Only the last 30 s of COP data were analyzed to remove amplitude distortion from signal filtering and to exclude initial postural adaptations when standing on the rocking board. We calculated path length of COP trajectory, in mm, (see Prieto et al.[35] formula 8) as the primary performance outcome in the postural control task, with higher values indicating poorer performance. For proportional DTC, we used the formula: DTC = (ST performance – DT performance) / ST performance x 100. DTC for the postural task was multiplied by –1 to reflect the inverse relationship between path length and postural performance. Higher DTC reflected greater decline in performance.

To assess the regularity of the COP trajectory, we used sample entropy, which is a dimensionless measure defined as the negative natural logarithm of the estimated conditional probability that data subsets of length m which repeats itself within a tolerance r will also repeat themselves for $m + 1$ points, disallowing self-matches.[25] Based on the guideline on optimizing the input parameters m and r proposed by Roerdink et al.,[25] we determined that $m = 3$ and $r = 0.02$ were optimal to maintain accuracy and discriminative power of the sample entropy estimate. These values are consistent with the lone study that applied sample entropy in assessing postural control of II-adults with Down syndrome.[27] We computed for sample entropy from the resultant COP time series using the routine from PhysioNet.[36]

We computed mean scores from all trials within the same experimental conditions. A mixed-factors ANOVA was conducted to evaluate differences in performance between conditions with impairment group (II- versus CT-athletes) as between- and task context (ST versus DT) as within-subjects factors. We also compared DTCs between tasks with impairment group (II- versus CT-athlete) as between- and task (cognitive versus postural tasks) as within-subjects factors to assess task prioritization. Significant interaction effects were further evaluated using post-hoc *t*-tests. Lastly, we assessed relationships among COP parameters using Pearson product-moment correlation coefficients. Two-tailed level of significance was set at $P \leq 0.05$.

3. RESULTS

3.1 Cognitive and postural performance in ST and DT contexts

Figure 1A shows group differences in cognitive-task performance. The mixed-factor ANOVA for the cognitive task revealed a significant main effects of task context, $F(1, 56) = 19.2$, $P < .001$, $\eta_p^2 = .26$ and group, $F(1,56) = 38.9$, $P < 0.001$, $\eta_p^2 = 0.41$, and a significant task context x group interaction, $F(1, 56) = 5.1$, $P = 0.03$, $\eta_p^2 = 0.08$. As expected, memory accuracy was worse in DT compared to ST context and CT-athletes outperformed II-athletes. Post-hoc *t*-tests indicated that II-athletes performed significantly worse than CT-athletes in both ST, $t(56) = –4.8$, $P < 0.001$, $\eta^2 = –0.29$, and DT contexts, $t(56) = –6.6$, $P < 0.001$, $\eta^2 = –0.43$. However, a groupwise comparison of task context effects revealed that while II-athletes showed a reliable decline in accuracy in DT compared with ST contexts, $t(28) = 4.0$, $P < 0.001$, $\eta^2 = 0.12$, this effect was not robust for CT-athletes, $t(28) = 1.9$, $P = 0.06$, $\eta^2 = 0.03$.

< *insert **Figure 1** here* >

For the postural task (see Figure 1B), we obtained no significant main effect of group, $F(1, 56) = 1.4$, $P = 0.25$, $\eta_p^2 = 0.02$, but the main effect of task context, $F(1, 56) = 12.0$, $P = 0.001$, $\eta_p^2 = 0.18$, on COP path length and task context x group interaction effect, $F(1, 56) = 4.3$, $P = 0.04$, $\eta_p^2 = 0.07$, were significant. Paired *t*-tests conducted post-hoc demonstrated improved postural control in DT compared with ST conditions in II-athletes, $t(28) = 3.2$, $P = 0.004$, $\eta^2 = 0.08$, but not for CT-athletes, $t(28) = 1.5$, $P = 0.15$, $\eta^2 = 0.02$. No group differences were observed in either the ST, $t(56) = 1.73$, $P = 0.08$, $\eta^2 = 0.05$, or DT, $t(56) = 0.52$, $P = 0.6$, $\eta^2 = 0.005$, conditions based on unpaired *t*-tests.

3.2 Postural control automaticity

Figure 1C shows sample entropy in participants' COP trajectories indicating the degree of automaticity in postural control. We found no significant main effects of task context, $F(1, 56) = 1.8$, $P = 0.18$, $\eta_p^2 = 0.03$, and group, $F(1, 56) = 3.5$, $P = 0.07$, $\eta_p^2 = 0.06$, for COP regularity as measured by sample entropy; however task context x group interaction was significant, $F(1, 56) = 8.4$, $P = 0.005$, $\eta_p^2 = 0.13$. Post-hoc *t*-tests revealed that CT-athletes' COP entropies increased reliably from ST to DT contexts, $t(28) = –2.5$, $P = 0.02$, $\eta^2 = –0.05$. In contrast, II-athletes' COP regularity showed no marked difference between task contexts, $t(28) = 1.5$, $P = 0.14$, $\eta^2 = 0.02$. As to group differences, post-hoc tests revealed reliably higher COP-entropy in CT- compared with II-athletes in the DT context, $t(56) = –2.6$, $P = 0.01$, $\eta^2 = –0.11$, while entropies were similar in the ST context, $t(56) = –0.8$, $P = 0.41$, $\eta^2 = –0.01$. This pattern of results suggests that CT-athletes were able to accommodate multitasking challenges by putting posture on "autopilot," which affords more automatic control. II-athletes, in contrast, prioritized posture and, if anything, trusted automatic control less under DT compared with ST conditions.

3.3 Proportional DTC

Figure 2 shows patterns of performance changes due to multitasking expressed as proportional DTCs for the two task domains (cognitive and postural) for the two athlete groups. The benchmark for proportional dual-task costs is a value reliably different from zero in one-sample *t*-tests. According to this criterion, only II-athletes demonstrated robust DTCs in both cognitive, $t(28) = 3.5$, $P = 0.001$, $\eta^2 = 0.10$, and posture tasks $t(28) = –3.1$, $P = 0.004$, $\eta^2 = –0.08$. For CT-athletes, neither cognitive, $t(28) = 1.9$, $P = 0.06$, $\eta^2 = 0.03$, nor postural, $t(28) = –1.6$, $P = 0.13$, $\eta^2 = –0.02$, DTCs were reliably different from zero. A mixed-factor ANOVA revealed a main effect of task, $F(1,56) = 35.5$, $P < 0.001$, $\eta_p^2 = 0.39$ and a task x group interaction, $F(1,56) = 9.5$, $P = 0.003$, $\eta_p^2 = 0.15$. Follow-up *t*-tests revealed that II-athletes' DTCs in the cognitive task were significantly higher than in the postural task, $t(28) = 5.4$, $P < 0.001$, $\eta^2 = 0.20$. Thus, our analyses of proportional DTCs provided clear evidence that II-athletes prioritized posture over cognition under multitasking conditions at the expense of pronounced costs for the cognitive task. For CT-athletes, we did not find solid evidence for DTCs in either task given that their DTCs did not reliably differ from zero.

*< insert **Figure 2** here >*

3.4 Correlations among ST and DT measures of postural control

Scatterplot matrix and correlation coefficients are shown in Figure 3 with CT-athlete data above and II-athlete data below the diagonal. Besides the expected correlations between ST and DT path length in both groups, we see only one significant correlation in II-athletes (i.e., ST–DT sample entropy). In contrast, that correlation is robust but lower in CT-athletes, Fisher $z = 2.9$, $P = 0.004$. Importantly, in CT-athletes correlations between entropy and path length were significant and were higher in DT condition. No such relationships were observed for II-athletes.

*< insert **Figure 3** here >*

4. DISCUSSION

The current study is one of the very few studies to investigate the impact of II on posture-cognition DT performance in a sample of high-level II-athletes and training volume-matched CT-athletes. In line with cognitive performance deficits expected from II-athletes, recognition accuracy in the memory task shows that CT-athletes were superior to II-athletes in both ST and DT contexts. As for postural performance, II-athletes showed similar bipedal postural stability (based on COP path length) as CT-athletes in both ST and DT conditions. This is contrary to our expectations and earlier findings of postural control problems, as well as higher prevalence of falls, in the II-population across the lifespan.[37,38] The absence of group difference in postural control between II- and CT-athletes can be attributed to methodological differences between the current and previous gait and posture studies, particularly regarding postural task and postural control measure used. Additionally, other studies have not focused on healthy young II-athletes. Intervention studies using a variety of sport or movement activities for II- and non-II-individuals have reported positive results.[37,39] In the present study, II-athletes' postural control may have benefited from the practice of sports.

Considering that the practice of sport indeed promotes better postural control and postural performance of II-individuals is generally worse than that of non-II-individuals, the lack of difference in postural performance between II- and CT-athletes have some important implications. First, sports training may enable II-individuals to achieve non-II levels of postural performance, provided that training volume is comparable to the participants in the current study. One of the purported causes of poor postural control in the general II-population is physical inactivity.[37] II-athletes overcome this by adopting, for extended durations, more physically active lifestyles tied to sport training and competition. This contributes to the general betterment of their postural control. It should be mentioned, however, that this may be true only to a certain extent. Van Biesen et al.'s[17] study reported that, compared to CT-athletes, II-athletes had worse postural performance in a more demanding one-legged balance beam standing task. Second, the extent of improvement in postural control resulting from sport training may be unequal for II- and non-II-athletes. Because II-individuals' poor postural control,[37] they have more room to improve and thus benefit greatly from training. In contrast, non-II-individuals have unimpaired postural control to begin with and any postural control benefits from sport participation may be too minute or specific to the sports they exercise that it cannot be detected by the present study's postural task. Several reviews[40,41] suggested this more nuanced effect of sport on postural control. It was noted that gains in postural performance are affected by level of expertise (i.e., superior postural control is more appreciable in international-level athletes than novice athletes and non-athletes) and that these gains may be specific to the sport which the athletes train for and compete in (e.g., elite surfers and gymnasts have better postural control in dynamic and unipedal standing conditions, respectively but neither athlete groups are any better than non-athletes in static bipedal standing).[40,41] Thus, in terms of postural control, II-individuals may have more to gain than non-II-individuals by being active and doing sports.

Although there were no overall difference in postural control between II- and CT-athletes, the introduction of a concurrent cognitive task demonstrated the differential response of the two athlete groups to multitasking. In terms of proportional DTC, we observed that II-athletes showed the expected decline in cognitive performance from ST to DT context, in line with our hypothesis. Results in the postural task, which was contrary to our hypothesis, indicated that II-athletes had smaller COP path lengths in DT compared to ST context and therefore had better postural performance in DT (i.e., negative DTC). While we did not expect improved performance from ST to DT, several studies on athletes[42] and non-athletes[43,44] have reported similar improvements in postural performance with the addition of a cognitive task. These findings have been explained using the *constrained-action hypothesis*, which suggests that a concurrent cognitive task draws attention away from the postural task thereby allowing the highly automatized postural control system to self-regulate.[45] This hypothesis, however, do not adequately explain our findings when COP sample entropy data is considered. Because automaticity of postural control is associated with increased COP irregularity,[42,44] we should expect an increased COP sample entropy in DT context. However, accompanying the decrease in COP path length, we found no significant change in II-athletes' sample entropy from ST to DT. It is likely that the addition of a cognitive task on top of the already challenging postural task placed a burden on the postural control system rather than relieve it from the constraint of attentional control. As a result, II-athletes may have opted to cognitively supervise and limit the amount of permissible sway (i.e., decreased COP path lengths) as a compensatory strategy to safely avoid falls in DT context. This interpretation aligns more with the *dual process account* of cognition-posture interference. The model considers the effect of task difficulty and individual differences in cognitive resource pool on whether cognitive tasks facilitate or deteriorate postural control.[43]

The strategy of II-athletes to preserve postural performance was also apparent when we compared DTCs between the cognitive and postural tasks. The higher DTC in the cognitive compared to the postural task demonstrated that II-athletes prioritized postural stability on the rocking board at the expense of the memory task. To minimize risk of bodily harm when concurrent tasks compete for cognitive resources, a *posture first* strategy is typically employed especially by older adults and patients with neuromusculoskeletal impairments whose postural capacity are diminished.[11,12] Our results provide evidence that II-individuals have the capacity for compensatory prioritization. Faced with a challenging memory-posture DT, II-athletes sacrificed cognitive performance to avoid increased postural instability by reducing total COP excursion.

Meanwhile, findings on CT-athletes showed DTCs in the cognitive and postural tasks that were not significantly different from zero. Sustaining ST-level cognitive and postural performance in DT context was likely possible for CT-athletes who, unlike II-athletes, are able to activate additional cognitive resources to compensate the extra challenges of the DT context. The availability of resource reserves in CT-athletes was made possible because the cognitive task was relatively simple for CT-athletes but already a considerable challenge to II-athletes. A second but not necessarily alternative source of resource reserves is hinted by COP sample entropy findings.

Entropy increased although path length stayed the same from ST to DT in CT-athletes, indicating an unconstrained and less cognitively supervised postural control.[24,25] Putting postural control on "autopilot" afforded more automatic control. This freed up cognitive resources that can be diverted to other tasks (e.g., concurrent cognitive task) and consequently protected CT-athletes from incurring DTCs when multitasking.

The relationship between COP measures in ST and DT contexts were generally in line with our hypotheses. For CT- and II-athletes, ST–DT sample entropy showed significant positive correlation but the correlation between them was significantly higher in II-athletes compared to CT-athletes. This suggest that the degree of automaticity of postural control in II-athletes were highly stable and relatively unaffected by task manipulations, while CT-athletes demonstrate adaptive capacity for task-related fine-tuning in this aspect of postural control. Agreeing with our assumption that adapting the degree of automaticity in postural control represents postural adaptation to task demands, correlations between sample entropy and path length were significant but only in CT-athletes. Few studies have explored the relationship between entropy measures and traditional linear COP parameters (e.g., path length) and these studies have yielded inconsistent results, with reports of non-significant correlations[46] and significant negative correlations that associate lower size or velocity of COP excursion with higher entropy.[47,48] These contrasting findings likely stem from differences in participant characteristics, postural and/or DT methodologies, and COP entropy or linear measures and may hint at the complexity of interpreting sample entropy. More research is necessary to understand further the relation between sample entropy and traditional measures of postural control, especially for II-individuals.

Our study provided evidence on differences in cognitive-motor DT performance between II- and CT-athletes. CT-athletes were able to accommodate multitasking challenges by drawing upon cognitive reserves and switching their postural control to a more automatic mode, allowing the preservation of postural and cognitive performance levels from ST to DT. In contrast, II-athletes did not show this accommodation. II-athletes instead adopted a posture first strategy resulting to significant cognitive DTCs and persistently relied on a cognitively supervised control of posture as they limit COP excursion. The limitation of this posture first strategy and inflexibility in adapting the degree of automaticity in the control of upright posture becomes apparent in sports situations where cognitive tasks (e.g., visually tracking your opponents and teammates or mentally deciding on tactics) take precedence over postural control. Based on our findings, the adaptive capacity to accommodate greater postural instability while preserving performance on the concurrent cognitive task determined CT-athletes' superior cognitive-postural DT performance over II-athletes. Sensitivities of II-athletes to multitasking interference were not compensated for by either athletic competence or potential transfer of athletic skill to domain-general cognitive functions.

Several study limitations are worth mentioning. First, the recruited II-athletes only have mild to moderate II and thus results may not generalize to other athletes with more severe II or with comorbid conditions like Down syndrome. Second, matching athletes from self-reported lifetime accumulated training volume is not the most ideal because, even if the reported number of hours are accurate, other variables like training intensity and quality of coaching and training influence athletic performance. Third, the lack of calibration of the cognitive task made it so that, as mentioned earlier, II-athletes found the memory task difficult while CT-athletes were nearing the ceiling score. Future studies should examine whether DTCs and prioritization strategies would be the same when cognitive tasks are individually calibrated.

5. PERSPECTIVE

Cognitive-postural multitasking is an essential component for success in many sports. The capacity for multitasking draws heavily on cognitive resource[10] and is, thus, particularly vulnerable to cognitive impairments[11] (e.g., II-individuals). Faced with multitasking, our results show that II-athletes prioritized postural stability, which allowed their performance to be comparable to CT-athletes'. This highlights the potential of physical activities, and competitive sports specifically, to improve poor postural control that is typical among II-individuals across the lifespan.[37] However, this postural stability came at the expense of memory performance, which deteriorated during multitasking. This disadvantages II-athletes in critical sport situations where information processing related to postural control is secondary to technical and/or tactical elements of a given sport. The impact of II-athletes' cognitive limitations on multitasking persisted despite their athletic competence or potential transfer of athletic skill to domain-general cognitive functions.

Acknowledgments

The study was supported by the Flemish Fund for Scientific Research (grant no. G0C6817N). The authors would like to thank the athletes and their coaches for participating in our research. We also thank Virtus and Fédération Française du Sport Adapté for their logistical support in this research and Janne Kerremans, Lore Jacobs, Adriana Marin Urquiza, Dries Jacobs and Niels Dobbelaere for assisting with recruitment and testing.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request, within the constraints of privacy and consent.

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TABLE 1. Summary of study participants' characteristics.

Characteristics	**II-athletes** **(*n* = 29)**	**CT-athletes** **(*n* = 29)**
Sex, M / F	24 / 5	24 / 5
Mean age, years	25.4 (6.0)	24.3 (6.2)
Mean IQ*	60.7 (7.2)	112.9 (14.1)
Mean BMI, $kg \cdot m^{-2}$	23.7 (5.5)	23.7 (2.6)
Mean lifetime accumulated training hours ‡	5170.7 (3492.7)	4037.1 (2098.2)

*Statistically significant difference between group ($P \leq 0.05$) based on independent *t*-test;

‡Calculated by multiplying training hours per week, total years of training, and 52.14 weeks per year. Figures in parentheses are standard deviations; II, intellectual impairment; CT, control group; IQ, intelligence quotient; BMI, body mass index.

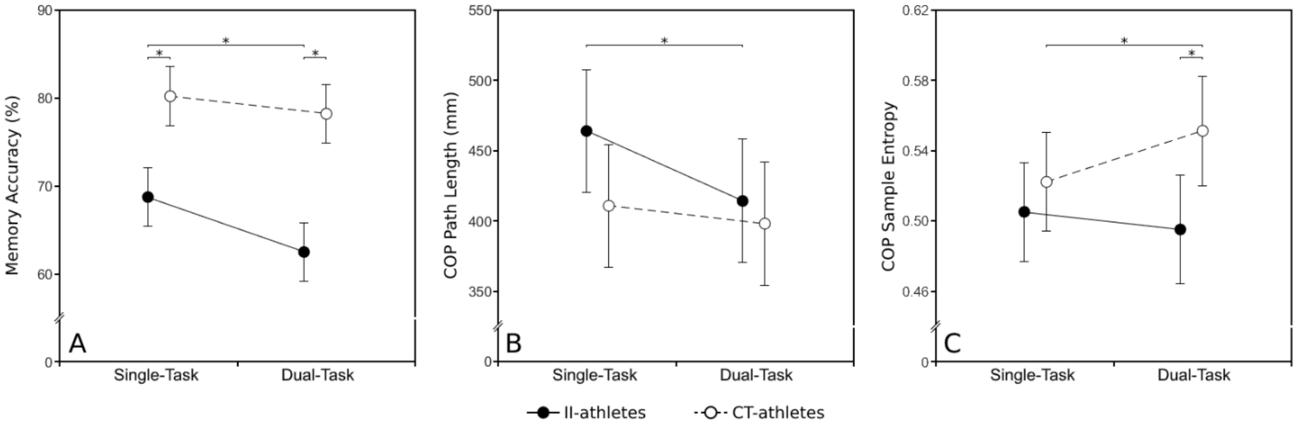

Figure 1. Memory accuracy (A) in the cognitive task and path length (B) and sample entropy (C) of center-of-pressure (COP) trajectory in the postural task for the single- and dual-task contexts. Error bars reflect 95% confidence interval. *Statistically significant. II, intellectual impairment; CT, control group.

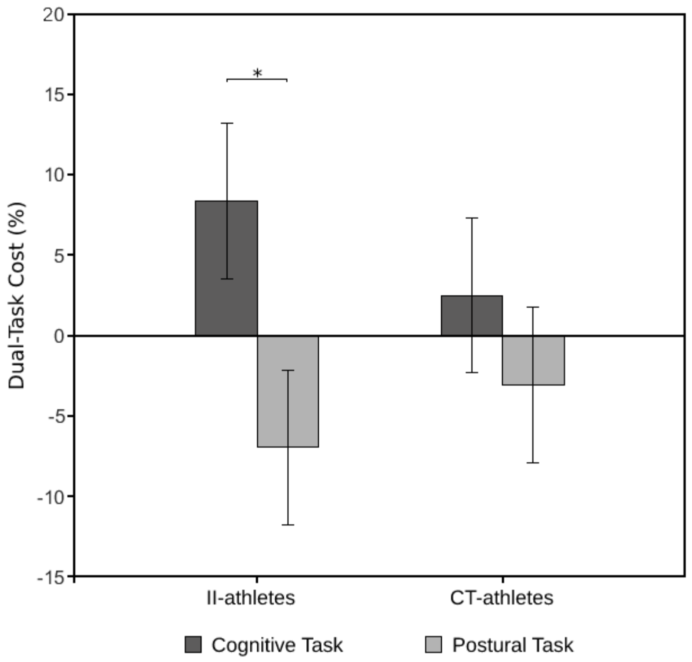

Figure 2. Proportional dual-task costs for the cognitive and postural tasks. Postural dual-task costs were multiplied by –1. Error bars reflect 95% confidence interval. *Statistically significant. II, intellectual impairment; CT, control group.

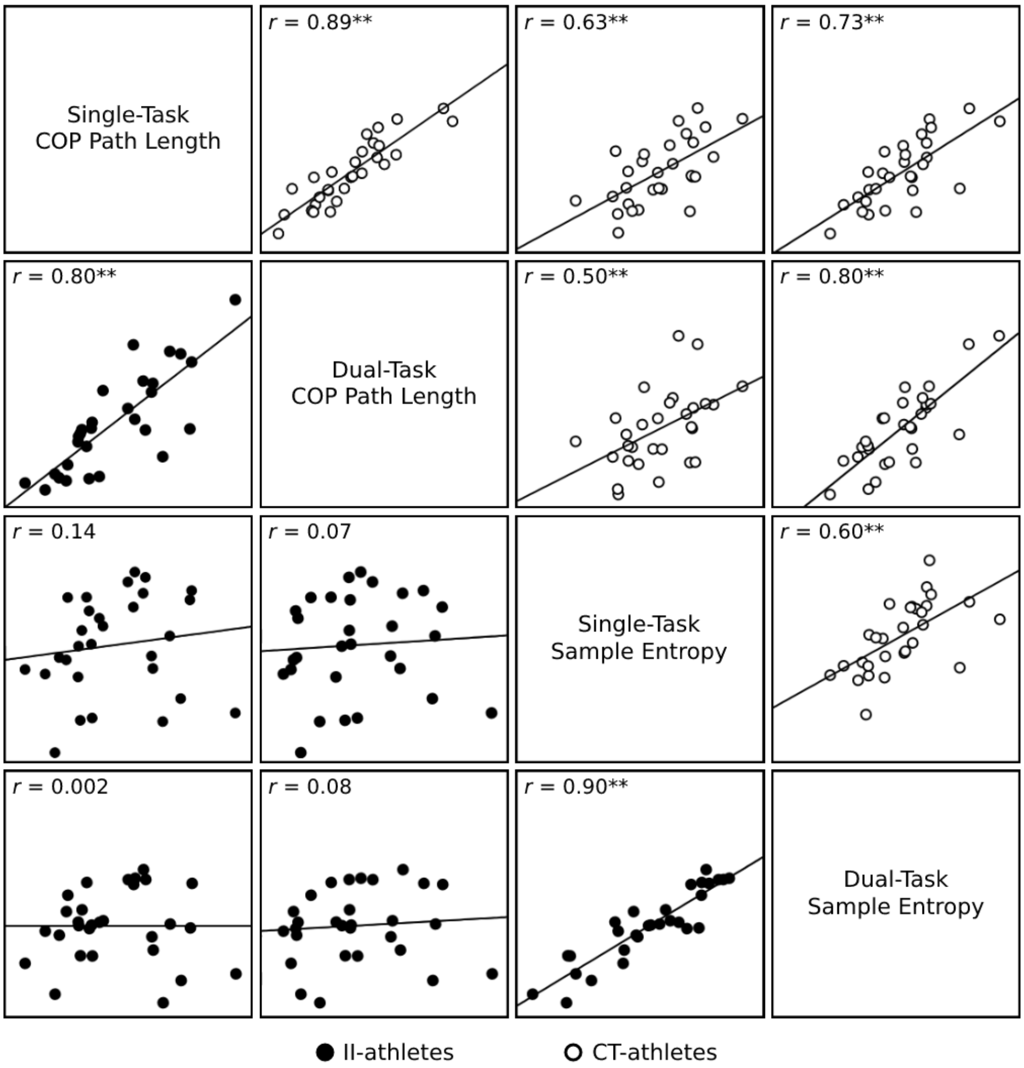

Figure 3. Scatterplot matrix of single- and dual-task measures of postural performance in II-athletes (athletes with intellectual impairment) and CT-athletes (athletes without intellectual impairment), along with corresponding Pearson product-moment correlation coefficients. **Significant correlations at *P* ≤ 0.01. COP, center of pressure