TITLE:

Cognitive-motor dual-task ability of athletes with and without intellectual impairment

RUNNING TITLE:

Dual-tasking in II-athletes

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ABSTRACT

Cognition is important in many sports, for example making split-second-decisions under pressure, or memorizing complex movement sequences. The dual-task (DT) paradigm is an ecologically valid approach for the assessment of cognitive function in conjunction with motor demands. This study aimed to determine the impact of impaired intelligence on DT performance. The motor task required balancing on one leg on a beam, the cognitive task was a multiple-object-tracking (MOT) task assessing dynamic visual-search capacity. The sample included 206 well-trained athletes with and without intellectual impairment (II), matched for sport, age and training volume (140 males, 66 females, M age = 23.2 ± 4.1 years, M training experience = 12.3 ± 5.7 years). In the single task condition, II-athletes showed reduced balance control ($F=55.9$, $p<.001$, $\eta^2 = .23$) and reduced MOT ($F=86.3$, $p<.001$, $\eta^2 = .32$) compared to the control group. A mixed-model ANCOVA revealed significant differences in DT performance for the balance and the MOT task between both groups. The DT costs were significantly larger for the II-athletes (-8.28% versus -1.34% for MOT and -33.13% versus -12.89% for balance). The assessment of MOT in a DT paradigm, provided insight in how impaired intelligence constrains the ability of II-athletes to successfully perform at the highest levels in the complex and dynamical sport-environment.

INTRODUCTION

Being tall, fast and physically fit is required to reach the elite level in basketball (Hoffman, Tenenbaum, Maresh, & Kraemer, 1996); and top swimmers combine a wide arm span with a long trunk/short leg ratio, which creates a greater surface area in contact with the water (Epstein, 2013). Besides the well-known anthropological and physiological key determinants of sports performance, intelligence also seems to be an influencing factor in many sports (Abbot, Collins, Martindale, & Sowerby, 2002). The awareness about the relevance of cognitive resources in sport is increasing over the last decade (Fernandes et al., 2016; Chaddock, Pontifex, Hillman, & Kramer, 2011; Diamond, 2000; Voss, Kramer, Basak, Prakash, & Roberts, 2010). A recent systematic review by Van der Fels et al. (2014); demonstrated a strong relationship between fluid intelligence and bilateral body coordination in 4-16 year typically developing children. They concluded that some cognitive skills (e.g., visual processing) are highly required in complex motor tasks. A Meta-Analysis, performed by Mann, Williams, Ward, & Janelle (2007), showed that expert sport performers possess enhanced perceptual-cognitive skills, such as effective attention allocation. Several studies have demonstrated that elite athletes elicit better visual-search strategies in comparison to their less skilled counterparts (Vaeyens, Lenoir, Philippaerts, & Williams, 2007; Williams & Reilly, 2000). Studies in young children registered positive correlations between maximal cardiorespiratory fitness ($VO_2\text{max}$), cognitive control, selective attention and visual memory (Chaddock et al., 2011). The overall assumption is that ‘body’ (= motor proficiency) and ‘mind’ (= cognitive resources) are related; however, until recently there has been limited knowledge about the precise nature of this relationship. Diamond (2000) argued that some of the brain regions previously thought to be exclusively related to motor activity (e.g., the cerebellum) or cognition (i.e., the prefrontal cortex) are co-activated during the execution of specific cognitive or motor activities. An under-investigated area of research is to what extent

impaired cognition might constrain the ability to perform high-level competitive sport; even though it is a crucial question in evidence-based classification of athletes with intellectual impairment (II) in the Paralympic Games (Tweedy, Mann, & Vanlandewijck, 2016).

A recent study by Van Biesen, Mactavish, McCulloch, Lenaerts, & Vanlandewijck (2016) examined the cognitive profiles of young well-trained athletes with and without II by means of nine subtests assessing their executive functioning and cognitive ability measures relevant to sport (e.g., fluid reasoning, short-term memory, reaction and decision speed, visual processing). All subtests were performed in single task (ST) conditions. The intention was to identify the relevant cognitive determinants of sport proficiency, with results outlining that the group of II-athletes performed significantly below their non-II counterparts on all measures. As limited cognitive resources seem related to sport proficiency, the performance of II-athletes will likely remain affected by their underlying impairment, no matter how hard they train. However, on an individual level, a small number of II-athletes in that same study obtained higher scores on one or two cognitive ability measures compared to the average norm values in the reference population without II.

In most sports, athletes frequently encounter situations in which they must perform multiple tasks simultaneously (Huang & Mercer, 2001); for instance memorizing the sequence while controlling balance on the balance beam, or dribbling while screening the field of play to give a possible assist in soccer. Therefore, cognitive functions will be assessed by means of a Dual-Task paradigm; which is considered an ecologically valid method, reflecting the actual situation in the dynamic sport environment (Schaefer, 2014). Dual tasking (DT) is defined as the simultaneous performance of two tasks with distinct goals (McIsaac, Lamberg, & Muratori, 2015). A number of factors (age, skill level, nature of the tasks) influences the attentional demand of the concurrent dual tasks. It is known that even highly practiced activities (e.g., maintaining postural control) are attention demanding,

especially in individuals with impairments. For example, Mohan, Singh, and Mandal (2001) found that the interference effect (i.e., the inability to perform two tasks concurrently when these two tasks involve similar brain regions) was larger in adolescents with mild II (IQ 55-75), compared to age- and sex-matched controls without II. The tasks involved a finger-tapping task and a verbal and nonverbal listening task. Orsolini, Melogno, Latini, Penge, and Conforti (2015) performed a case study with a 14-year-old boy with mild II, who changed from being incapable of addressing the DT request in the initial assessment to performing close to normal limits after a 2yr intensive training program. Another training study with a larger sample of 34 adolescents with moderate II (mean IQ = 45.15 ± 3.39) found positive effects of DT training on postural stability (Mikolajczyk & Jankowicz-Szymanska, 2015). However, in general there is a lack of studies investigating DT in individuals with II compared to a control sample without II.

The DT-method has proven to be an appropriate way to evaluate the skills of athletes from various sports; including rugby (Gabbett, Wake, & Abernethy, 2011) and Taekwondo (Chen-Kang, Chen, Dai, Chen, Chou, & Chang, 2015). Athletes and sportive individuals (without disabilities) demonstrated superior DT performance compared to novices, even in situations where expert-novice differences were not evident on the primary ST (Gabbett & Abernethy, 2012).

To investigate how II-athletes allocate cognitive resources during sport, a realistic environment is needed in which they perform a cognitive task in combination with a motor task. Different theoretical models exist to explain the mechanisms of motor – cognitive interactions (Wollesen, Voelcker-Rehage, Regenbrecht, & Mattes, 2016; Lacour, Bernard-Demanze, & Dumitrescu, 2008 for a review). The cross-domain competition model states that postural control and cognitive activity compete for attentional resources, leading to performance decrements (dual task costs; DTC) in DT conditions, and a negative effect of DT

on postural control. However, a more complex interaction model (U-shaped) states that the postural stability can either be improved or diminished depending on the higher or lower cognitive demands of the cognitive task (Lacour et al., 2008), with low demanding cognitive tasks shifting the focus of attention away from postural control and leading to increased automatic processing of posture. A third and final model, is the task prioritization model, mainly derived from literature in the elderly (Lacour et al., 2008; Schaefer, 2014), who tend to prioritize postural control over cognitive-task performance, mainly as a strategy to avoid falls. So far, none of the three models seems to be able to explain all the results on postural control in DT conditions. However, all these results point to the direction that DT is definitely influenced by a number of external factors such as the type of the motor task (static or dynamic), the type and complexity of the cognitive task, and also a number of internal factors such as the cognitive ability of the participants.

The cognitive task selected for this investigation is a multiple object tracking (MOT) task, with gradually increasing cognitive load. Mental tracking tasks refer to tasks that require holding information in the mind while performing a mental process and they have usually been used to examine sustained and divided attention and visuospatial processing speed (Lezak, Howieson, Bigler, & Tranel, 2012). The motor task is a modified Flamingo balance task, which is a static (standing), but challenging task (one leg, narrow support), relevant to many sports and physical activities. (Oja & Tuxworth, 1995). It is known that persons with II, in comparison with peers without II, demonstrate impaired tracking skills (Brodeur, Trick, Flores, Marr, & Burack, 2013; O'Hearn, Hoffman, & Landau, 2010; Cabaral, Beaton, Stoddard, & Simon, 2012) and also greater postural instability; as indicated by a larger, more variable and more laterally orientated body sway pattern (Enkelaar, Smulders, van Schrojenstein Lantman, Geurts, & Weerdesteyn, 2012). The ability to successfully combine

MOT and balance tasks has not yet been investigated in II-athletes. In the present study, a unique examination of existing knowledge gaps will be initiated.

The main goal of this study is to investigate how II-athletes allocate resources in DT conditions. The first aim is to explore the available cognitive resources in ST conditions. It is known that even simple postural tasks require cognitive resources (Lacour et al., 2008). Therefore, the hypothesis is that II-athletes have reduced balance control, and worse MOT skills compared to equally well-trained athletes without II. Possible gender differences are also explored. The second aim is to investigate the differences in motor-cognitive DT-performance between athletes with and without II. In the DT conditions without specific instructions to prioritize any of the tasks, we hypothesize that II-athletes have limited resources to successfully combine cognitive demands with the fundamental motor skill. Therefore, we hypothesize performance decrements for the motor and the cognitive task in the DT versus ST condition, with significantly larger decrements for II-athletes compared to non-II-athletes. The final aim is to explore the relation between cognitive load and DT performance in both groups. The hypothesis is that DTC's increase as the difficulty level of the MOT magnifies, and we expect a faster increase for the II-group.

METHODS

Participants

A total sample of 206 athletes participated in this study. The first group consisted of 103 II-athletes (33 females and 70 males, $M_{IQ} = 60.6 \pm 9.2$, $M_{age} = 24.4 \pm 5.8$ years, $M_{training\ experience} = 11.4 \pm 7.0$ years, $M_{training\ sessions/week} = 4.2 \pm 2.5$, $M_{training\ volume/session} = 2.2 \pm 1.2$ hours).

Athletes were recruited during the Global Games in Ecuador, September 2015, a high level competitive event, organized by the International Federation of intellectual disability sport

(INAS). All athletes met the criteria for diagnosis of II (AAIDD, 2010): significant limitations in adaptive behavior and intellectual functioning with an $IQ \leq 75$, both manifested before age 18. None of the participants had severe or profound II, or a known chromosomal disorder (e.g., Down syndrome). The detailed IQ and adaptive behavior data of the participants were retrieved from the INAS database. INAS recognizes the most recently standardized versions of the Wechsler Intelligence Scales (WISC and WAIS), Stanford-Binet and Raven Progressive Matrices. The participants represented nine different countries (Australia, USA, Mexico, The Netherlands, Ecuador, France, Portugal, South-Africa, and Japan) and participated in six different sports, as indicated in Table 1: basketball ($n=34$), football ($n=26$), cycling ($n=5$), swimming ($n=25$), tennis ($n=9$) and athletics ($n=4$).

The control group consisted of 103 athletes without II (33 females and 70 males, $M_{age} = 22.0 \pm 2.4$ years, $M_{training\ experience} = 13.3 \pm 4.4$ years, $M_{training\ sessions/week} = 3.5 \pm 1.6$, $M_{training\ volume/session} = 1.60 \pm 0.34$ minutes). Every individual without II was matched with an II participant based on gender, involvement in the same principal sport and comparable level of expertise in that sport. The level of sport expertise of the athletes was calculated from the data, self-reported by the athletes and their coaches, including the total years of previous involvement in the sport, and the average number of sport practice/training per week, as reported in Table 1 for both samples. The total level of sport expertise per athlete was expressed in accumulated number of training hours across the entire lifespan, and calculated by means of the formula: $[\#years\ of\ involvement * 52\ (weeks/year) * \#training\ sessions/week * \#hours/training\ session]$. Having an II was eliminated by including participants who, at a minimum, had graduated from regular secondary education. All participants in the control group had Belgian nationality. They were recruited in local sport clubs and at the university sports faculties. A written informed consent was obtained from all participants before the start of the experiment. The Medical Ethics Committee of the KU Leuven approved the study.

Instruments

Flamingo balance test

To evaluate the participants' ability to balance successfully on one leg (static balance control), a modified Flamingo Balance Test (FBT) was used (Oja, & Tuxworth, 1995). Participants were instructed to stand on a metal beam (50 cm long, 5cm high, 3cm wide, and stabilized by two supports at each end with a non-slip surface), on the preferred leg, wearing sport shoes or sneakers, arms hanging at their side. Whilst balancing on one leg, the participant was prohibited to touch the support leg or the ground with the free leg. Prior to test initiation the participant remained stable by holding the instructor's shoulder. The test was started when the free foot was released from the floor and the hand removed from the shoulder. The duration of the test was 60 seconds, recorded with a stopwatch by a trained test-instructor. The stopwatch was paused and un-paused each time the participant lost and re-gained balance. When the participant required more than 15 attempts during the first 30 seconds, the test was terminated and a zero-score registered. To promote focus during the test, a computer screen displayed a white circle on a black background at participant's eye-height. The beam was placed at a standardized distance from the screen (two times the screen width measured from the middle of the beam). After finishing the first trial with the preferred leg, the test was repeated with the non-preferred leg.

Multiple object tracking test

The multiple object tracking test (MOT) was originally developed by Pylyshyn & Storm (1988), with a huge body of literature involving various types of MOT tasks emerging since then (for an overview see Scholl, 2009). An adapted version of the MOT was developed for

the purpose of the present study by engineer L.J. Reliability (ICC = .85) was assessed in $n=200$ young healthy adults (Vos & Vanspeybroeck, 2015). The test was projected on a computer screen with a resolution of 1024x768p (19-inch), with a black tracking field occupying the entire screen. Participants were in standing position, with the center of the screen adjusted to eye-height and both feet placed at hip width, at a standardized distance from the screen (two times screen width). The aim of the test was to track target objects that were randomly moving among distracters. For each trial, 1-4 flashing green circles would appear (size= 1.4° and angle of view= 28°) with simple red distractors. Here, the participant was instructed to focus on the flashing green circles. Once the participant indicated to be ready, the circles all became red and start to move following independent trajectories on the screen for 10 seconds. When the circles stopped moving, random numbers appear adjacent to them, with the participant subsequently asked to identify the original flashing green target(s) by saying the number or pointing to the target circle. The selected targets were designated by the instructor and feedback immediately appeared on the screen by means of a good or wrong sign. If an error was made by the participant, the instructor selected the correct targets to finish the trial and move on to the next trial. After three standardized demonstration trials, a standardized sequence of maximum 15 trials was presented, with gradually increasing level of difficulty, depending on three alterable parameters: the number of targets (from 1-4), the number of distracters (from 1-7) and the speed of the targets and distracters (from $2^{\circ}/\text{sec}$ to $10^{\circ}/\text{sec}$) (see Table 1). The first four trials (T1-T4) included one single target to track, the subsequent four trials (T5-T8) included two tracking targets, the subsequent four trials (T9-T12) included three targets, and the final three trials (T13-T15) included four tracking targets. The MOT finished when three errors were made in three different trials, or after completion of the 15th trial.

Dual Task (DT)

In the DT test, the FBT and MOT were performed simultaneously. Participants were asked to perform the complete MOT test whilst standing on their preferred leg on the balance beam, and instructed to perform both tasks to the best of their ability. The sequence of 15 MOT trials was identical to the ST condition. For every trial, the test instructor pressed the MOT start button as soon as the participant indicated to be ready by releasing the free foot from the floor and/or removed the hand from the instructor's shoulder. In between 10 sec trials, the participant was allowed to relax with both feet on the floor. For each trial, the number of attempts needed to complete 10s was recorded by the instructor. The test was finished when 15 trials were completed or when a total of three MOT errors was made. The DT MOT score equals the total number of MOT trials solved correctly; the DT balance score is the average time (in seconds) the participant is able to stay on the beam, with a maximum of 10 seconds, equalizing a perfect score.

Procedure

Data collection consisted of one test session, involving four phases, with a total duration of approximately 30 minutes per session. In the first phase, the participants signed an informed consent and they all completed a questionnaire concerning age, sport activity, training history and training volume. Parents' consent was required if the participants were younger than 18. In the second phase (single balance), the FBT was performed once for each leg, starting with the preferred leg. The third phase involved assessment of MOT performance in ST condition, and the final phase was the combined assessment of FBT and MOT in DT condition. The testing of the control sample took place in the universities' Research & Development lab. Three similar testing labs were installed at the athletes' hotel, during the Global Games competition, in three quiet rooms, free from any distractions.

Data analysis

All statistical analyses were performed with IBM SPSS Statistics, version 22, with level of significance set at $p < .05$. The variables included in the analyses for the cognitive test are MOT score (ST and DT; total number of correct items; max 15), MOT error (ST; number of correct items until first error; max 15). The variables for the motor task are balanceNON-DOM (ST) and balanceDOM (ST and DT; average time on the beam per attempt in seconds, respectively with dominant and non-dominant leg, max 10). To be able to compare balanceDOM between ST and DT conditions, a perfect score was awarded when the participant was able to stand on the beam for 10 seconds or more. For the ST condition, this corresponds to a maximum of 6 attempts per 60 seconds trial.

To assess differences in performance in the ST condition, a 2x2 ANCOVA analysis was performed with group (II versus non-II) and gender (male versus female), controlling for age as covariate.

To assess the differences in performance between ST and DT conditions, mixed model analyses were performed for MOT and FBT separately, with condition as the within factor, impairment as the between factor, and age as the covariate. Six participants with II dropped out (3 males, 3 females), as they failed to perform the balance test on the beam ($n=3$) or lacked the motivation to complete the test session until finish ($n=3$).

In order to compare performance during DT across groups and tasks, DTC's were also reported. DTC is expressed relative to performance during ST as a percentage, and calculated according to the following formula:

$$\text{DTC} = 100 * \frac{\text{ST performance} - \text{DT performance}}{\text{ST performance}}$$

RESULTS

Appropriate data screening techniques were used to confirm the assumptions underlying the statistical analyses used. Besides the homogeneity of variances, all the normality assumptions were met. Because of the large sample sizes in the present study, the assumption of normality can be permitted and parametric statistics can be used without danger of altering the results (Ghasemi & Zahediasl, 2012).

Single task performance

A 2x2 way ANCOVA was used to examine the effect of impairment (with II versus without II) and gender (male versus female) on balance and MOT in the ST conditions, controlling for age. The results of the analysis are presented in Table 3. ST performance of II-athletes was significantly worse compared to athletes without II for both tasks ($P < .001$), with medium to large effect sizes reported for BalanceDOM ($\eta^2 = .23$), BalanceNonDOM ($\eta^2 = .26$), ; MOT ($\eta^2 = .32$), and MOTerror ($\eta^2 = .27$). Gender differences were found for the MOT task with males performing better than females on the total MOTscore ($\eta^2 = .04$, $p = .01$) and on the MOTerror ($\eta^2 = .03$, $p = .03$). No gender differences were observed for the balance task and no gender x impairment interaction effects were significant for any of the variables assessed.

Single versus dual task comparison

Figure 1 shows the performance pattern for the two tasks for the ST and DT conditions. The repeated measures ANCOVA for the cognitive task revealed a significant

main effect for condition, $F(1,199) = 4.93, p=.03, \eta^2= 0.02$, indicating performance decrements for MOT in the DT condition. A significant main effect for the between factor impairment was also found, $F(1,199) = 131.67, p<.001, \eta^2= 0.40$, indicating overall better performance for the non-II group. The significant condition x impairment interaction effect revealed that II-athletes had larger decrease in performance on the cognitive task compared to non-II-athletes, $F(1, 199) = 10.43, p<.001, \eta^2= 0.05$.

The repeated measures ANOVA for the balance task revealed a significant main effect for the within factor condition, $F(1, 191) = 5.71, p=.02, \eta^2= 0.03$, indicating reduced postural control in the DT condition. A significant main effect for the between factor impairment was also found, $F(1, 191) = 103.91, p<.001, \eta^2= 0.35$, indicating overall better postural control for the non-II group. A significant interaction effect condition x impairment for balance revealed that the performance decrement for balance was significantly larger for II-athletes compared to non-II-athletes, $F(1, 199) = 28.31, p<.001, \eta^2= 0.13$.

Relation between cognitive load and cognitive task performance

Figure 2 presents the results of the 2 (impairment: II vs non-II) x2 (condition: ST versus DT) x 4 (number of tracking targets) ANCOVA with repeated measures on the latter factor. The error rate increased significantly with increasing number of tracking targets, $F(1, 190) = 72.5, p<.001, \eta^2= 0.53$. A significant main effect of condition revealed that error rate was larger in DT compared to ST trials, $F(1, 190) = 4.6, p = .03, \eta^2= 0.02$, and the significant main effect for the between factor revealed larger error rate for II versus non-II athletes, $F(1, 190) = 134.6, p<.001, \eta^2= 0.41$. Two way interaction effects were found for condition x

impairment, $F(1, 190) = 9.4, p = .002, \eta^2 = 0.05$, targets x impairment ($F(1, 190) = 41.7, p < .001, \eta^2 = 0.39$), and condition x targets ($F(1, 194) = 3.9, p = 0.01, \eta^2 = 0.06$). The three way interaction effect 'condition x impairment x targets' was significant, $F(1, 190) = 7.0, p < .001, \eta^2 = 0.10$, indicating a faster incline in error rate in the DT condition versus ST condition; however, only for II-athletes, whereas non-II athletes have a slower incline in error rate in ST and DT conditions (see Figure 2). In both conditions, athletes without II have none to very low error rates in trials with one target (0% ST, 0.2% DT) or two targets (3.2% ST, 6.3% DT); somewhat higher error rates in three-target trials (23.3% ST, 27.9% DT), and up to 77.3% (ST) and 75.7% (DT) error rate in four-target trials. II-athletes follow a similar pattern of incline at higher error rates from one to four targets (6.2% - 21.9% - 67.5% - 95.2%) in the ST condition; whereas in the DT condition a steep, progressive incline in error rates was observed between trials with one target (8.3%) over target with two trials (42.3%) to trials with three (76.0%) and four targets (94.8%).

DISCUSSION

The present study was conducted to investigate the ability of II-athletes to successfully perform a complex and dynamic cognitive task in conjunction with a gross motor task with the purpose of unraveling the relationship between body (motor proficiency) and mind (cognitive function). Therefore, we applied the cognitive-motor DT paradigm (cognitive mental tracking task in combination with a static balance task) to two samples of athletes with and without II. As expected, we found reduced mental tracking skills and reduced balance control for II-athletes compared to non-II-athletes in the ST condition, and the differences between both samples became even more apparent in the DT condition. For athletes with II, the DTC increased more dramatically compared to the ST performance with increasing cognitive load of the MOT task (more moving targets to track).

Single task performance

We assessed MOT and balance control under ST conditions first, and as expected we found reduced balance control and reduced tracking skills in II-athletes compared to the athletes without II. With respect to the reduced tracking skills, this finding is supported by several other studies, involving people with specific types of IIs. Affected tracking skills have been demonstrated in populations with different types of II. For example, in young (18-38 years) people with Williams Syndrome, with an IQ ranging from borderline mild (60-80) to moderate (35-50) (O'Hearn, Landau, & Hoffman, 2010), children (7-14 years) with 22Q.11.2 deletion syndrome ($IQ = 77.5 \pm 11.0$) (Cabral et al., 2012) and young people (age = 15.1 ± 3.4) with Down syndrome (Brodeur et al., 2013) respectively.

It is known that high level athletes typically perform better on MOT tasks compared to novices as, to execute this test well, a set of cognitive skills is required (e.g., attention, working memory, visuospatial awareness and concentration) that play a role in a sport context

(Gabbett & Abernethy, 2012). A study by Faubert (2013) showed that there is a clear link between athletic performance (in soccer, ice hockey and rugby players) and mental capabilities needed to perform the MOT. They demonstrated that professional athletes (N=51) in their study performed significantly better on a 3-dimensional MOT task, and they also learned the task faster compared to amateurs (N=173), who, in turn differed from non-athlete students (N=33) in their capacity to learn the complex dynamical visual task. On the other hand, cognitive functions required to perform the MOT; namely attention, concentration and visuospatial constructive skills, appear to be delayed in persons with genetic-based intellectual disabilities (Di Nuovo & Buono, 2009). The results of the present study suggest that sport expertise cannot fully compensate for the II, and the mental tracking skills of the II-athletes are constrained more by their impairment, than they are compensated by their sport expertise. Further research is required to confirm this, preferably a longitudinal study or randomized control trial.

With respect to the reduced balance control in II-athletes, the present finding is also supported by the literature, as reduced balance control is often reported in adolescents and adults with II (see Enkelaar et al., 2012, for a review). For example; Blomqvist, Olsson, Wallin, Wester, and Rehn (2013) demonstrated reduced postural control in 100 adolescents with II (aged 16-20 years, IQ between 35-70), compared to age-matched peers. They used a battery of three dynamic and two static balance tests, including the single leg stance, which is similar to the FBT used in the present study. Whereas our finding is not surprising; however, the present study was one of the first in which balance was assessed in a large group of well-trained II-athletes. Very few studies with limited methodological quality have addressed trainability of balance and, to our knowledge, only one study demonstrated reduced body balance, assessed by means of the Flamingo Balance test, in a sample of 313 world-class II-

athletes (Van de Vliet et al., 2006). Hence, it remains unclear whether the poor balance control of people with II should be attributed to extrinsic causes (e.g., their lower level of physical activity), or to intrinsic causes (e.g., the inadequate development of the central nervous system) or to a combination of both (Patikas, 2015). It is impossible in this stage to draw conclusions regarding the positive effects of sport expertise reducing the differences in balance control between people with and without II. Apparently, balance remains affected, even when two equally well-trained groups are compared.

Single versus dual task comparison

The DT paradigm was used to investigate differences in how II-athletes allocate resources when performing cognitive and motor tasks concurrently, corresponding to the more realistic environment on the sport field. While performing the balance task and MOT task simultaneously, both the cognitive performance (less correct trials) and the balance control (decreased time on the balance beam) changed as compared to the ST condition. The DT performance decrements (DTC) were most apparent for the II-athletes. Various theoretical models attempt to explain balance performance under DT conditions, and one of the oldest models is the Limited Resource Hypothesis (Wickens, 1980), which assumes that there is a common pool of limited cognitive resources for both cognitive and motor tasks (Wollesen et al., 2016). The Cross-Domain competition Model was derived from this assumption and states that under DT conditions both balance control and cognitive tasks compete for identical brain resources, resulting in reduced balance control, reduced cognitive performance, or reduced performance on both tasks, with the latter corresponding to the findings in the present study. Even a rather simple postural task such as quiet standing requires cognitive resources (Lacour et al., 2008). In the DT condition, the participants were required to divide cognitive resources between two tasks; however, the capacity of the human brain is limited in processing

information in parallel (Lennie, 2003), and apparently even more limited in individuals with II, due to the nature of their impairment. In the study by Horvat, Croce, Tomporowski, and Barna (2013), for example; individuals with Down syndrome were less proficient in a walking test with an additional cognitive task, compared to participants without Down syndrome. The authors theorized that the motor program in individuals with Down syndrome was not sufficiently developed to adapt their movements to tasks requiring greater levels of information processing. Also in the study by Mohan et al. (2001), people with II were more prone to cognitive-motor interference by the DT demand characteristics compared to the control group without II. The task in that study was to combine a finger-tapping test with a verbal and a rhythmic listening task.

Relation between cognitive load and cognitive task performance

The cross-domain competition model cannot fully explain the influence of having/not having an II on the DT performance. Another model investigating the relation between postural control and cognitive performance is the U-shaped Non-Linear Interaction Model. This model postulates that the varying cognitive load of the cognitive task (X-axis) has an influence on the balance performance (Y-axis). The type of the cognitive task (e.g., spatial versus nonspatial), as well as the nature of the cognitive processes involved (e.g., visual versus auditory information processing) is assumed to influence balance performance (Maylor et al., 2001; Trick, Mutreja, & Hunt, 2012). A more or less challenging cognitive task might lead to reduced or improved balance in DT conditions (Wollesen et al., 2016). The cognitive load of the cognitive task in our study was initially low, but increased gradually across trials. The cognitive processes involved in mental tracking are sustained attention, working memory and visuospatial processing. Compared to the athletes with II, the non-II-athletes appeared to be more able to allocate the competing cognitive resources successfully to the DT demands.

Task prioritization

Although there was no specific instruction in the present study to prioritize any of the tasks, there is a third theoretical model worth mentioning in light of the present findings. The task prioritization model offers a further explanation for the observed differences between athletes with and without II in DT performance. The task prioritization model was originally developed to explain that performance in simultaneously performed tasks can vary greatly among individuals (Wollesen et al., 2016). Mostly from studies in elderly, it is known that older people assign the balance task a higher priority, especially when the balance task is challenging. They prioritize balance over cognitive task to avoid putting their balance at risk, at the expense of the cognitive task. Li et al. (2005) explained this as a compensatory reorganization of cognitive resources in the face of cognitive performance diminished by age. Schaefer et al. (2008) demonstrated the phenomenon of prioritizing postural control also in young children (9- 11-year-old), who were asked to combine balancing on an ankle-disc board, with a memory task, with difficulty level individually adjusted to the participant.

.Not only age, but also intellectual impairment influences the available cognitive resources; however, the II-athletes in the present study did clearly not apply the strategy to prioritize balance, as their motor task performance deteriorated with 33% in the DT condition, which is more than the cognitive task cost (8%). With respect to the maturity of the brain, the athletes with II might have more similarities with younger children (similar mental age) compared to adults (similar chronological age).

Limitations and further research

The present study was the first to apply the cognitive-motor DT paradigm to a large and unique sample of well-trained athletes with and without II. Some limitations to the present study need to be addressed. When comparing balance control between ST and DT conditions, it is important to keep in mind that the protocol was not identical, as several trials of 10s were provided in the DT condition, and one trial of 60s in the ST condition, later normalized to 10s for comparison. It was not the aim of the present study to find out which parts of the brain were involved in cognitive-motor DT. However, subsequent research concerning neuroanatomy and brain imaging (e.g., functional magnetic resonance imaging) should be considered. Another suggestion for further research is to compare the cognitive-motor dual-task ability between athletes with II and non-sportive individuals with II. That type of research design will provide insight in the potential impact of sport expertise on cognitive and motor performance.

Practical implications

Reduced balance control in II-athletes, even in the ST condition, is an important finding, as balance control is one of the two most important human motor skills (in combination with gait) required for mobility (Patikas, 2015). Any impairment on the development of these motor skills does not only deteriorate sport performance, but also reduces the level of independence and increases the need for support to perform daily activities. Insight in the mechanisms underlying balance deficits in people with II will contribute to develop evidence-based interventions and training programs, improving their quality of life. Furthermore, if a mind (cognition) – body (balance) relationship can be disentangled and understood in this population, motor interventions may be developed to help reduce their cognitive deficits, help

improve their balance control, and stimulate their potential to effectively and successfully combine multiple tasks.

On top of the previous implications, the fundamental research question addressed in this study aligns with a larger international research initiative that aims to develop evidence-based systems of eligibility and classification in the Paralympic Movement. The reduced performance of II-athletes compared to non II-athletes in ST and DT conditions supports the need for a separately organized competition, as II-athletes will not be able to reach the same level of performance in sport as elite athletes without II.

CONCLUSION

The results of this study demonstrated poorer dynamic visual search abilities in II-athletes compared to athletes without II, most apparent in DT conditions. Visual search assessed in combination with balance revealed a greater distinction between both groups in comparison to the ST. Therefore, this kind of dynamic visual search test, used in a DT paradigm, has the potential to provide insight in the cognitive function of well-trained athletes with II, participating in international competitive events. This study revealed that visual perception, which is one of the components of cognitive function, relevant to sport, is severely reduced in II-athletes. Furthermore, people with II seem to have reduced balance control, even if they are physically active, well-trained and participating in high level sport competitions. These findings can help to determine the impact of II on sport performance.

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Table and Figure Captions

Table 1. Participants' Characteristics

Table 2. Multiple object tracking test specification of demonstration and test trials

Table 3 Comparison of cognitive and motor performance in the single task condition, with age as covariate.

Figure 1: Comparison of mean scores between Single Task – Dual Task conditions in the II and non-II-samples for the Cognitive Task (Multiple Object Tracking) and Motor Task (Balance). Note. MOT = Multiple Object Tracking, , II = intellectual impairment.

Figure 2: Percentages of incorrectly solved trials in the II and non-II group on each difficulty level of the multiple object tracking (MOT) task in single-task and dual-task conditions. Note. II = intellectual impairment, * $p < .05$

Table 1

Participants' characteristics

	With II			Without II		
	Male	Female	Total	Male	Female	Total
Total (N)	70	33	103	70	33	103
Sport (N)						
Athletics	4	0	4	4	0	4
Basketball	17	17	34	17	17	34
Cycling	5	0	5	5	0	5
Soccer	26	0	26	26	0	26
Swimming	15	10	25	15	10	25
Tennis	3	6	9	3	6	9
Accumulated training volume (<i>M</i> hours $\pm$ <i>SD</i>)						
Athletics		6474.0 $\pm$ 7539.0			5915.0 $\pm$ 2569.5	
Basketball		3688.6 $\pm$ 3111.5			3042.0 $\pm$ 1428.4	
Cycling		9188.4 $\pm$ 7631.7			9305.4 $\pm$ 8486.6	
Soccer		2426.1 $\pm$ 1375.6			3505.0 $\pm$ 1865.0	
Swimming		7763.0 $\pm$ 5467.5			4857.8 $\pm$ 2789.3	
Tennis		3068.0 $\pm$ 2483.9			2241.8 $\pm$ 1649.9	
Age (<i>M</i>)	25.0	23.3	24.4	21.4	20.5	21.1
Age (<i>SD</i>)	6.0	5.4	5.8	2.6	1.9	2.4

Note. II = intellectual impairment

Table 2 Multiple object tracking test specification of demonstration and test trials

Item	#Targets	#Distracters	Speed (°/s)
Demo 1	1	1	1
Demo 2	2	2	2
Demo 3	3	3	3
Trial 1	1	1	1
Trial 2	1	1	2
Trial 3	1	2	3
Trial 4	1	4	4
Trial 5	2	4	2
Trial 6	2	4	3
Trial 7	2	2	4
Trial 8	2	4	5
Trial 9	3	3	4
Trial 10	3	5	3
Trial 11	3	5	4
Trial 12	3	4	4
Trial 13	4	4	4
Trial 14	4	4	4
Trial 15	4	4	5

Table 3 Comparison of cognitive and motor performance in the single task condition, with age as covariate.

	Non-II <i>M</i> (SD)			II <i>M</i> (SD)			N	<i>F_i</i> (<i>p</i>)	η^2	<i>F_g</i> (<i>p</i>)	η^2
	Female	Male	Total	Female	Male	Total					
BalanceDOM (sec, max 10)	9.7 (0.8)	9.9 (0.7)	9.8 (0.7)	7.3 (3.1)	8.1 (2.5)	7.9 (2.7)	193	55.9 (<.001)	.23	3.2 (.08)	.02
BalanceNON- DOM (sec, max 10)	9.8 (0.6)	9.7 (1.4)	9.7 (1.2)	7.2 (3.2)	7.6 (2.6)	7.5 (2.7)	193	64.3 (<.001)	.26	2.1 (.15)	.01
MOT _{score} (total# correct trials, max 15)	11.3 (1.7)	11.8 (1.6)	11.6 (1.7)	7.5 (2.6)	8.8 (2.8)	8.3 (2.8)	190	86.3 (<.001)	.32	7.8 (.01)	.04
MOT _{error} (correct trials until 1st error, max 15)	10.9 (2.5)	11.8 (2.4)	11.5 (2.5)	7.5 (2.7)	8.3 (3.1)	8.0 (2.9)	190	66.6 (<.001)	.27	5.1 (.03)	.03

Note. II = intellectual impairment, MOT= multiple object tracking,
DOM=dominant leg, *F_i* = F-value impairment, *F_g* = F-value gender, η^2 =
Partial eta squared effect size.