The impact of intellectual disability and sport expertise on cognitive and executive functions

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ABSTRACT

Background: Having an intellectual disability (ID) can interfere with proficiency in certain domains of executive function (EF), such as inhibition, set-shifting and working memory updating; which in turn has implications for sports performance. The aim of this study was to identify the potential suitability of three EF assessment tools (i.e., Flanker test, Word span update, and Color-trail test) for future inclusion in the classification process of elite Paralympic athletes with ID; and to assess the strength of the relation between EF and intelligence in that population.

Methods: Cognitive and EF assessments were performed on 59 participants, divided into four groups according to their cognitive level (ID versus non-ID) and sport-expertise (athlete versus novice).

Results: Participants with ID scored lower on inhibition and working memory update compared to people without ID; whereas for set-shifting, a more nuanced picture was observed. Our study revealed stronger associations between EF and intelligence measures within the sample of people with ID compared to people without ID. No significant differences according to the level of sport expertise were found.

Conclusions: Considering the requirements related to finding the optimal battery of EF tasks suitable for use with people with ID within the context of elite sports performance, our study identified the Flanker task as a feasible task to assess inhibition. Working memory updating and set-shifting are also important EF skills to assess in this context; however, culture free alternatives for the Word Span update test are needed, and alternatives to the Color-trail test, less reliant on literacy skills are required.

Keywords: inhibition, set-shifting, working memory updating, intellectual impairment, Paralympic sports

INTRODUCTION

In everyday life, people regularly face complex situations in which they have to make split second decisions or plan in advance, both consciously and unconsciously. These situations require complex executive functioning. Executive functions (EF) are the high-level cognitive processes that enable an individual to deal successfully with novelty and change in social and non-social settings, and to regulate their thoughts and actions during goal-directed behavior. People utilise EF to initiate and generate plans, to prioritise actions and to assist in self-monitoring and evaluation of behavior (Friedman & Miyake, 2017). Several domains of EF have been identified, such as working memory (WM), planning, set-shifting, updating, inhibition and attentional control. Each domain has its specific characteristics and relevance depends on the task and context in which they are required.

. There is ongoing debate in the literature around the question whether EF and general intelligence are distinct or overlapping constructs, and some researchers assume that EF is closely related to fluid intelligence (e.g., inductive reasoning and perceptual speed) (Arffa, 2007; Salthouse, 2005). However, Friedman and Miyake (2017) performed an extensive literature review exploring the relation between EF and intelligence in adults. They found distinct differences and concluded that some EF domains (e.g., updating) are more related to intelligence than other EF domains (e.g., inhibition and shifting) (Carretti, Lanfranchi, De Mori, Mammarella, & Vianello, 2015). For children who still have immature neurocognitive abilities, a different picture has been reported. All three types of EF equally predicted both fluid and crystallized intelligence (Brydges, Reid, Fox, & Anderson, 2012).

The role of cognition in sports performance has been increasingly acknowledged. During the last decade, researchers and practitioners in sport and exercise psychology have shown increased interest in EF among top athletes (Elferink-Gemser et al., 2018; Ishihara, Sugasawa, Matsuda, & Mizuno, 2017; Torbjörn Vestberg, Reinebo, Maurex, Ingvar, & Petrovic, 2017).

At the most elite level of sports for athletes with intellectual disabilities (ID), i.e., the Paralympic Games, an evidence-based classification system is used to detect the impact of impairment on sport performance (Van Biesen, Mactavish, McCulloch, Lenaerts, & Vanlandewijck, 2016). A core element of Paralympic classification is demonstrating that the impairment, in this case intellectual disabilities, has an impact on the performance of a specific sport (International Paralympic Committee, 2015). Currently three sports in the Paralympics, i.e., athletics, swimming and table tennis, include athletes with ID. Across these sports, a generic computerized test battery is used to assess the athletes' sport intelligence, which is defined as the relevant aspects of cognition implicated in sports performance (Van Biesen et al., 2016). The purpose of the test battery is to determine eligibility of athletes with ID to compete in the Paralympic Games. This eligibility is based on demonstrable cognitive impairment, in line with what can be expected in athletes with ID and which impacts their sports performance. As cognitive functions with a higher cognitive load (including EF) are more implicated in sport performance compared to lower level cognitive functions (van der Fels et al., 2015; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012), it was decided that the Sport intelligence Test should include measures of EF. Additional requirements for the selection of subtests in the Sport Intelligence Test were related to the practical feasibility of administrating the test in an international sample of athletes with ID, at different sporting events across the world. The cultural diversity of the sample and testing situations required the chosen tests to have a limited verbal component, to be free of cultural bias, and to be administered and stored on a portable device. Other constraints on test choice were related to the athlete's intellectual impairment. For instance, traditional EF tests are often too challenging as they include complex tasks and instructions, potentially causing floor effects (Masson, Dagnan, & Evans, 2010).

For the assessment of EF within the Sport Intelligence Test, a computerized version of the Tower of London (TOL) test, adjusted for ID, was initially selected because it is one of the most frequently used tests to assess planning. The TOL provides graded levels of difficulty and a variety of qualitatively different problems (Unterrainer, Rahm, Halsband, & Kaller, 2005). The validity of using adapted TOL versions in a population of people with ID was supported by Masson et al. (2010). However, the test-retest reliability of the TOL was found to be low in a sample of 104 athletes with ID, with significantly improved performance on the retest (Van Biesen et al., 2016). Low reliability is a common problem identified in EF assessment, as the novelty of the situation is a crucial element of EF performance, which decreases with repeated assessment. In addition to the low reliability, the TOL looks specifically at only one aspect within the broad domain of EF, i.e., planning skills.

Since the development and initial use of the Sport Intelligence Test in classification, a growing number of studies examining EF, its structure and its implications in sport have emerged. Besides planning, several researchers (Jacobson & Matthaeus, 2014; Vestberg et al., 2012) have found evidence indicating the relevance of EF to sports, with similarities as well as significant differences across sports. Even within one sport, athletes use different EF skills according to their distinct disciplines or roles. For example in soccer, different cognitive profiles are required for different playing positions, with midfielders needing stable EF over a long time period, attackers need more set-shifting when reacting quickly and impulsively, and defenders rely mostly on inhibitory functions (Vestberg et al., 2012).

Apart from taking into account the demands of a sport, it is crucial to consider the specific characteristics related to their cognitive impairment when searching for valid and reliable assessment tools to assess EF in elite athletes with ID (Van Biesen et al., 2021). It has been demonstrated that the intellectual impairment of people with ID can interfere with proficiency in certain EF domains, including planning, inhibition, set shifting, updating and working memory (Ball, Holland, Treppner, Watson, & Huppert, 2008; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Menghini, Addona, Costanzo, & Vicari, 2010). For the current study, we focused on three core executive functions—inhibition, working memory updating and set-shifting—which are all lower-level processes implicated in other higher-order functions, such as planning (Miyake et al., 2000).

Inhibition is defined as the ability to ignore irrelevant stimuli while performing an additional task. It includes the ability to change and/or stop an action, behavior or response when this is not desirable (Friedman & Miyake, 2017; Miyake et al., 2000). Inhibition is often assessed with a Stroop-like Task, in which the delay in reaction time between congruent and incongruent stimuli (e.g., ink colour versus word colour) gives an indication of interference and processing speed. Simplified versions of this task, such as the Day and Night version (Lanfranchi et al., 2010) are available for use with young children or clinical populations who are not proficient in reading; although the test still requires verbalisation. A non-verbal alternative that also meets the criteria of being culture free and portable was chosen for this study to assess inhibition, i.e., the Eriksen Flanker paradigm. In this task, the participants have to focus on one stimulus while ignoring the distractors (i.e., flankers). The adjusted Flanker test selected for this study was previously used successfully in young soccer players with ID (Chen et al., 2019), high performance athletes with ID (Van Biesen, McCulloch, Janssens, & Vanlandewijck, 2017), and non-sport-participants with Fragile X syndrome, Down Syndrome, and other types of ID (Shields et al., 2020).

Working memory (WM) refers to a broad framework of interacting processes that involve the temporary storage and manipulation of information in the service of performing complex cognitive activities (Baddeley, 2012). WM can be assessed with short-term retrieval tasks (Lanfranchi et al., 2010; Walley & Donaldson, 2005). There is some ongoing debate concerning the question whether WM is part of general intelligence or part of EF (Chevalère et al., 2015; Lanfranchi et al., 2010). The task selected for this study was a 'WM updating' task, in which participants have to recall the smallest objects in a list of words in the correct order of representation. Updating requires additional cognitive processes, i.e., the ability to modify the content of memory dynamically according to task requests (Miyake et al., 2000; Morris & Jones, 1990). Although the test requires verbalisation, culture free objects were selected, and it was demonstrated in a study by Carretti et al. (2015) that the updating word span task had the greatest power in discriminating between children with and without ID that were matched for fluid intelligence performance.

Finally, set-shifting is defined as the process of switching between different tasks and mental sets (Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002). Set-shifting tasks are designed to assess the ability to categorise or switch between two or more dimensions in a flexible way (Gaines & Soper, 2018). The trail making task (TMT) is a well-known paradigm to test set-shifting and it has been used in children with ID (Costanzo et al., 2013; Hartman, Smith, Houwen, & Visscher, 2017; Palmer, 2006). TMT requires a certain level of numerical and verbal proficiency from the participant, who needs to connect circles in an ascending pattern as quickly as possible, alternating between numbers and letters (e.g., 1-A-2-B-3-C etc.). A simplified version, i.e., the colour TMT, is selected for the use in this study, as it only requires numerical literacy not verbal literacy, which is often confounded in the population of people with ID (McDuffie, Thurman, Channell, & Abbeduto, 2017).

The overall purpose of this study was to search for a better alternative to the TOL for the Sport Intelligence battery, to be used in the Paralympic classification process of elite athletes with ID. The three domains of EF relevant to sport (i.e., inhibition, WM updating, and set-shifting) were investigated by examining the potential suitability of three related assessment tools (i.e., Flanker test, Word span update, and Colour-trail test). The performance of an international population of elite athletes with ID on these three tests of EF was further considered in relation to standardised measures of intelligence, the absence of ID and the athletic aptitude of the athlete. Not much is known about EF in people with ID, and the strength of the association between EF and intelligence in this population was also investigated. Most of the research related to this topic, so far, was conducted in people with specific syndromes, such as Down Syndrome (Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Lanfranchi, Jerman, & Vianello, 2009) or Williams syndrome (Costanzo et al., 2013; Menghini et al., 2010), whilst this study included those a wider range of participants with ID.

The first research question was whether the Flanker task, WM updating and colour TMT have the potential to discriminate between samples of people with and without ID. We hypothesised a significant difference in EF across the three domains (WM, inhibition and set-shifting), with better EF performance of people without ID.

The second research question was how the three measures of EF are related to intelligence. We hypothesised a positive linear relation between EF and intelligence across the three EF domains, with stronger association between EF and the fluid intelligence subscale compared to EF and crystallized intelligence.

The third research question was whether or not there are differences in the EF-intelligence relation between people with or without ID. We hypothesised that there are no differences in the EF -intelligence association between people with or without ID.

Finally, we investigated whether or not there was a difference in EF profile based on sport expertise. As EF seems to be positively related to sport proficiency, we hypothesised that athletes have better EF skills compared to non-athletes.

METHOD

Participants

In total, 59 participants, divided in four groups according to their cognitive level (ID versus non-ID) and sport-expertise (athlete versus novice), took part in the study. The participants with ID (IQ≤75) were recruited through the national disability sports federation and contacts in day-care centres and recreational services for individuals with ID. None of them had Down syndrome. The non-ID group consisted of 30 participants who were recruited through sport clubs, universities, and personal contacts. Athletes in the sample trained ≥ 5 hours/week or have been training for ≥ 5 consecutive years. Additionally, athletes with ID competed at the international level while athletes without ID competed at local or national levels. The difference in competitive level between the ID and non-ID athletes was due to: (1) the disparity between training volume of athletes with and without ID who compete internationally, with the athletes without ID training substantially more than athletes with ID and (2) our intention to match the athletes groups on training volume. An overview of the participants' characteristics is reported in Table 1.

Table 1

Participants' characteristics

	with intellectual disability			without intellectual disability			TOTAL
	athlete	novice	total	athlete	novice	total	
N	14	15	29	15	15	30	59
Gender, M/F	10/4	10/5	20/9	11/4	10/5	21/9	41/18

Mean age in years (SD)	23.6 (5.3)	26.3 (4.6)	25.5 (5.5)	22.4 (4.6)	24.2 (6.4)	23.8 (5.4)
Mean IQ (SD)	64.4 (12.3)	60.5 (15.1)	62.4 (13.7)	117.9 (13.3)	116.5 (10.1)	117.2 (11.4)
Mean weekly physical activity in hours (SD)	9.1 (7.0)	2.7 (0.9)	5.8 (5.8)	7.3 (3.2)	1.8 (0.9)	4.6 (3.6)
Mean lifetime accumulated training hours* (SD)	2933.8 (2634.4)			2427.3 (1518.6)		

Note. Figures in parentheses are standard deviations; *calculated by multiplying training hours/week, total years of training and 52.14 (weeks to years conversion factor). M/F = Male/Female ration,

Materials/Assessment tools

Executive function measures

We assessed three EFs in this study: response inhibition, mental set shifting and working memory updating. Before the start of each test, the participants received a demonstration and practice trials to ensure that they understood the task.

The response inhibition was assessed using the Flanker test, as described by Van Biesen et al. (2017). In this adapted Flanker task, a stimulus consisting of a target stimulus (target arrow pointing up, down, right, or left) surrounded by four distractor stimuli (Flanker arrows) appeared on screen. The Flanker arrows, which all point to the same direction, could be either congruent or incongruent with the target arrow. We instructed the participants to tap on the keyboard’s arrow key that corresponded to the target stimuli as soon as they appeared on screen. We also added a visual search component to the test by having the Flanker configuration appearing at nine possible locations across the screen. During the 30-s duration of the test, a series of Flanker configuration appeared on screen at random interval from each other. The computer registered the number of correct and incorrect taps made in

30-s, for both the congruent and incongruent trials. To make sure the participants with ID understood the task well, the instruction was built up progressively, introducing first the requirement of reacting as fast as possible (simple reaction time task), afterwards introducing the visual search component and requirement of selecting the correct response among the four arrows (choice reaction time task), and finally introducing the inhibition aspect (Flanker task).

To evaluate mental set shifting, we used the Color Trails Test (D'Elia, Satz, Uchiyama, & White, 1996), which consists of two parts. In Color Trails 1, participants had to draw a line connecting encircled numbers 1 through 25, which were arranged randomly on the test sheet, in numerical order as quickly as possible. On the Color Trails 2 test sheet, all encircled numbers (excluding number 1) appeared twice—one in a pink circle and the other in yellow. Participants had to connect the 25 numbers while alternating between the two colours. Completion times (in seconds) of both parts was recorded. Before beginning the test, we asked the participants to write the numbers 1 to 25 while reciting them. Those who were unable to complete this prerequisite task did not proceed with the Color Trails Test. We calculated an interference score by subtracting the completion time of Color Trails 1 from Color Trails 2 and then dividing it by completion time of Color Trails 1.

We selected the updating word span task to evaluate WM updating and monitoring that was previously used with people with ID by Carretti et al. (2015), and translated it to Dutch. In this test, we orally presented lists of items which the participants had to recall based on the criterion "smallest object/s within each list" and in the order of presentation. The working memory load in this test progressively increases from level 1 (recall 1 item) to level 5 (recall 5 items), with each level having two trials. The number of items in each trial's word list is twice (trial 1) and two-and-a-half times (trial 2) the number of items to be recalled. Within each list, we incorporated concrete words that refer to objects easily comparable in size, have the same syllabic length, and are learned by most Dutch native speakers by the age of 6 years (Shao & Stiegert, 2016). A point was given for each correctly recalled item in the correct sequence, with a minimum score of zero and maximum score of 30 points on this test. The test was terminated when the participants earned a score of zero on both trials of a level. We implemented this stop criterion to avoid inducing frustration to low performers and still accommodate the large variation in performance between the individuals with and without ID

Intelligence and Intellectual function (IF) measures

The intellectual functions of the participants were assessed using the Wechsler Adult Intelligence Scale-III-NL (WAIS-II-NL) (Wechsler, 2005), according to standard test instructions. We used the scaled score of the vocabulary and matrix reasoning subtests, as a measure of crystallized and fluid intelligence, respectively. Furthermore, we also represented processing speed and working memory capacity using the scaled scores of the symbol substitution and digit span, respectively.

Procedures

The assessment of intelligence and EF was performed as part of a larger project investigating the effect of impairment and sport-expertise on static and dynamic postural control. Prior to enrolment, all participants (and respective staff nurse of their facility, in the case of participants with ID) underwent phone screening to collect demographic data, regular physical activity, and general health (e.g., recent illness and injuries, current medical concerns, medications). For the athlete groups, we also asked about their training and competition history. Each participant was tested individually in a quiet testing room, free from any distractions. For the intelligence and EF assessments, they sat at a table next to the test instructor. One research assistant was present in the room. The total protocol, including all motor and cognitive assessments involved two sessions of two hours with one hour break in between both sessions. Additionally, short breaks were given between each assessment. The EF assessments were performed at the start of the session in a fixed sequence for all participants, as follows: Flanker Test, Color Trails Test and Updating Word Span. We administered the vocabulary followed by the digit span before the one-hour break, while the symbol substitution and matrix reasoning were administered after the break. The total administration duration of all EF and IF tests ranged from 45 to 60 minutes, depending on the participant's level of performance. Study design and protocol were reviewed and approved by the UZ/KU Leuven Research Ethics Committee (B322201731833/S59931). All participants provided their written informed consent

Data analysis

Assumptions on normality and homoscedasticity were checked using Shapiro-Wilk and Levene's test, respectively. Data demonstrated significant deviations from normality with asymmetric distribution and homogeneity of variance between groups. Therefore, we used a combination of non-parametric and robust statistics to test our hypotheses.

Hypothesis 1: we investigated differences in EF and intellectual function (IF) between people with and without ID by means of the Yuen's two sample trimmed mean test (20% trimming), which is a robust alternative to the independent samples t-test when data that are not normal and heteroscedastic (Mair & Wilcox, 2019). Explanatory measure of effect size, ξ, which is analogous to the explanatory power of R2 from regression, is compatible with data with unequal variances. Small, medium and large effect sizes corresponds to $\xi = 0.15$, 0.35 and 0.50, respectively (Wilcox & Tian, 2011).

Hypothesis 2: the relation between EF and IF across the three EF domains was investigated by means of Spearman's rank-order correlation.

Hypothesis 3: Fisher's z comparisons were performed to compare the strength of the association between EF and IF measures within-group and between-group (Myers & Sirois, 2004). Effect size was reported as Cohen's q (Cohen, 1988).

Hypothesis 4: To evaluate the differences in EF, for the participants with ID, between those with and without sport expertise, we implemented a robust 2x2 ANOVA, using 20% trimmed means (Mair & Wilcox, 2019).

RESULTS

Hypothesis 1: ID versus non-ID differences in EF

The differences in EF between the groups of participants with ID versus without ID are presented in Table 2, with scores on all subtests expressed as the scaled scores. The hypothesis of a significant difference in EF across the three domains (WM, inhibition and set-shifting), with better EF performance for people without ID was supported. Only for the set-shifting interference score, no significant differences between groups were found (p = .841).

Table 2: Differences in executive function and intellectual function measures between people with and without intellectual disability (ID)

Characteristics	With intellectual disability (*n* = 29)	Without intellectual disability (*n* = 30)	T_y	*P*	ξ
Executive function					
Flanker	23.4 (8.9)	38.5 (3.2)	**T_y(21.8) = 9.01**	**< .001**	**.95**
Word Span	7.8 (4.2)	22.1 (4.8)	**T_y(32.3) = 12.5**	**< .001**	**.97**
Color Trails – interference	0.92 (0.52)	0.98 (0.38)	T_y(26.9) = 0.20	.841	.08
Color Trails – time1	60.5 (30.3)	25.7 (5.8)	**T_y(14.8) = 4.49**	**< .001**	**.76**
Color Trails – time2	108.3 (53.0)	49.7 (8.5)	**T_y(14.9) = 5.40**	**< .001**	**.84**
WAIS–III subscales					
Vocabulary	3.5 (3.2)	13.6 (2.5)	**T_y(29.8) = 15.44**	**< .001**	**.92**
Symbol Substitution	3.9 (2.7)	11.5 (2.5)	**T_y(35.0) = 11.01**	**< .001**	**.90**
Matrix Reasoning	3.4 (2.5)	11.6 (2.0)	**T_y(33.9) = 13.09**	**< .001**	**.94**
Digit Span	5.1 (2.7)	13.0 (2.6)	**T_y(35.0) = 11.36**	**< .001**	**.88**

Note. Figures in parentheses are standard deviations. WAIS = Wechsler Abbreviated Intelligence Scale

Hypothesis 2: strength of relation between EF and intelligence

The strength of the relation between EF and IF measures is presented in Table 3 and Table 4, for athletes with ID, and athletes without ID respectively. The hypothesis of a positive linear relation between EF and intelligence across the three EF domains, with stronger association between EF and the fluid intelligence subscale compared to EF and crystallized intelligence was partially supported.

Table 3: Spearman rho correlations between executive function and intelligence measures in people with intellectual disability (ID).

	1	2	3	4	5	6	7	8	9	10
1. IQ	1.00									
2. Flanker[a]	.83**									
3. Word Span	.62**	.48*								
4. CT – interference[b]	.07	.16	.20							
5. CT – time1[c]	.54**	.75**	.41*	.59**						
6. CT – time2[b]	.40	.65**	.22	.06	.78**					
7. Vocabulary	.82**	.56**	.49*	.11	.30	.13				
8. Symbol substitution	.78**	.76**	.42*	.12	.60**	.59**	.47*			
9. Matrix reasoning	.70**	.55**	.48**	.17	.64**	.53**	.49**	.52**		
10. Digit span	.92**	.81**	.66**	–.14	.39	.32	.70**	.68**	.54**	1.00

[a] *n* = 28; [b] *n* = 23; [c] *n* = 25; * $p < .05$, ** $p < .01$, CT = Color Trails

As can be observed in Table 3, there were some missing data in the sample of participants with ID, and all these came from the participants in the non-athlete group. One participant was not able to understand the instructions of the Flanker and CTT. Additionally, four participants did not complete both tests of the CTT while 2 other participants completed test 1 but not test 2 of the CTT. All the participants from the other groups completed all tests.

Table 4: Spearman rho correlations between executive function and intelligence measures in people without intellectual disability (ID).

	1	2	3	4	5	6	7	8	9	10
1. IQ	1.00									
2. Flanker	.42*									
3. Word Span	.43*	–.04								
4. CT – interference	–.05	–.10	–.13							
5. CT – time1	.16	.31	–.10	.57**						
6. CT – time2	.34	.43*	.01	–.15	.64**					
7. Vocabulary	.72**	.11	.38	.25	.12	.08				
8. Symbol substitution	.22	.37*	–.01	–.25	.14	.38*	–.20			
9. Matrix reasoning	.75**	.37*	.48**	.15	.24	.31	.57**	.11		
10. Digit span	.68**	.29	.20	–.19	0	.18	.33	–.12	.26	1.00

* *p* < .05, ** *p* < .01

Hypothesis 3: strength of relation between EF and intelligence, ID versus non-ID

The strength of the relation between EF and intelligence was compared between people with and without ID using Fisher z comparisons. The Cohen's q (effect size) can be interpreted as <.1: no effect; .1 to .3: small effect; .3 to .5: intermediate effect; >.5: large effect (Cohen, 1988)

Relation between overall IQ and EF scores:

The relation between IQ and inhibition (Flanker) is stronger for ID compared to non-ID, z = 2.67, p = .008, Cohen's q = .74.

For the relation between IQ and the other EF measures, no significant differences between ID and non-ID were found (z = 0.96, p = .337 for the IQ-working memory relation, and z = –1.54 p = .124 for the IQ-shifting interference relation).

Relation between EF measures:

The relation between inhibition and updating working memory is stronger for ID compared to non-ID, $z = 2.03$, $p = .042$, Cohen's $q = .56$.

The relation between inhibition and shifting (CT1) is also stronger for ID compared to non-ID, $z = –2.27$, $p = .023$, Cohen's $q = .65$.

A trend towards significance was found for a stronger relation between updating working memory and shifting in ID compared to non-ID ($z = –1.87$, $p = .062$)

Relation between working memory capacity (digitspan) and working memory updating (wordspan):

- Wordspan – Digitspan is significant, $z = 2.15$, $p = .032$, Cohen's $q = .59$

We hypothesised that there are no differences in the EF -intelligence association between people with and without ID. However, the results showed a large difference in the strength of the association between both groups, indicating larger associations in the group of individuals with ID.

Hypothesis 4: differences in EF between people with and without sport expertise

The robust 2x2 ANOVA revealed no significant differences between athletes and non-athletes, not for the main effect of sport expertise, nor any group versus sport expertise interaction effects.

DISCUSSION

In the current study, we sought to assess the feasibility and discriminative power of three EF measures for future use in the classification process of elite athletes with ID and to gain more insight into the strength of the relation between EF and intelligence in this sample. As expected, people with ID scored lower on inhibition and working memory update compared to people without ID. With respect to their set-shifting ability, a more nuanced picture is observed. Interestingly, our study revealed stronger associations between EF and intelligence measures within the sample of people with ID compared to people without ID. Finally, although the EF performance of athletes with ID is higher than for non-athletes, none of these observed differences were significant, probably because of the small number of athletes in the sample.

An adjusted Flanker task was used for the assessment of inhibition in this study. Research has consistently shown that the deficits in inhibition in children with ID are extensive in both verbal and non-verbal modalities. Inhibition is a commonly impacted sub-domain of EF that is impaired across different ID syndromes (Bhat, Sharma, & Jena, 2014). As expected, the participants with ID in our study showed decreased inhibitory control. Three interrelated processes are included in response inhibition, i.e., inhibition of the initial prepotent response to an event, stopping of an ongoing response and the interference control (Barkley, 1997). Inhibition is an important feature, allowing us to modify the well-learned responses when faced with situations in which alternative responses are required, such as those in sports. Therefore, inhibition was chosen for this study as one of the EF measures of interest. In several sports, athletes should be able to ignore the irrelevant stimuli and only focus on the relevant stimuli for optimal performance. For example, in table tennis it is important to identify the relevant cues from the environment (e.g., the position of the opponent, and the position of the opponent's arm and racket) to anticipate the action of the opponent and prepare the appropriate reaction (Faber, Bustin, Oosterveld, Elferink-Gemser, & Nijhuis-Van der Sanden, 2016). In several sports, specifically during competition, with presence of an audience, it is also important that the player can focus on the task, and follow the coaches' guidelines, while ignoring the presence of the spectators. Similarly, in other sports (e.g., soccer), it is crucial that defenders are able to respond correctly when attackers feign a movement or shoot toward the opposite direction. The Stroop task is well-known and often used in the scientific literature to measure inhibition. However, for this study a non-verbal task was chosen, because the non-verbal aspect aligns closer to the sports context, and is also more suitable for the use in a population of international athletes with an ID. The Flanker task is also part of the US National Institute of Health (NIH) toolbox, which is a cognitive battery including measures of EF, that has been validated in various target groups, including people with ID (Hessl et al., 2016).

The results of our study showed that all but one (n=28) of the participants with ID were able to perform the task and were able to understand the instructions. We facilitated comprehension by gradually building up the instructions towards the final task, to make sure all participants were aware of what was required; and concepts were introduced one step at the time (Debbie Van Biesen et al., 2017).

To summarise, inhibition seems to be a relevant EF skill to include in the context of elite ID-sport classification and the adjusted Flanker task is a valid and feasible option to assess it.

Working memory update was assessed by means of a verbal updating word span task, which revealed a significantly worse performance on this EF domain in people with ID, as hypothesised. This finding builds on the work of Carretti et al. (2015), which demonstrated that updating is a task with great discriminative power to detect group difference between children with ID and typically developing children, matched for fluid intelligence.

Depending on the specific demands of the sport, athletes need to remember smaller or larger units of information to perform well; hence, it is known across a broad range of sports that working memory is implicated in performance (Furley & Memmert, 2010). In a competitive environment, athletes must remember everything they learned during training and practice (e.g., technique, tactics, strategy). While on the field of play, for example in basketball, the players have to memorise the commands of the coach. Due to the dynamic nature of sport the memorised commands and learnt behaviours must be constantly updated in relation to the changing context. This cognitive skill is clearly apparent in team sports, but may also be implicated in other sports such as running events in athletics, where adjustments may need to be made to pacing and positioning strategy in relation to the actions of others. As such, it is an important skill to include in the generic Sport Intelligence Test, and the results from this study demonstrated the task and items were accessible and open to further cross-cultural development and testing.

Furthermore, at a more granular level, a distinction needs to be made between working memory capacity and working memory updating. Capacity refers to the amount of information that can be stored in the brain. For the purpose of evidence-based classification, the Corsi test is currently integrated in the Sport Intelligence Test, to assess how many units of information an athlete can hold in the brain (D. Van Biesen et al., 2016). Elite athletes with ID can store on average four units of information compared to the norm of seven in equally well-trained athletes without ID. Working memory updating goes beyond the basic cognitive levels, as it refers to the manipulation of information that is stored. Non-verbal alternatives to assess this EF task are scarce; therefore including the working memory updating task, adjusted for the population of people with ID, provides an additional dynamic dimension to assessing EF.

The results of our study revealed that working memory update is related to measures of intelligence, both in the population of people with and without ID. Interestingly, a stronger relation between memory capacity and memory updating was found in people with ID compared to the non-ID population. The operations required in a typical working memory update task consist of three components, i.e., retrieval, transformation, and substitution (Ecker, Lewandowsky, Oberauer, & Chee, 2010). Ecker et a (2010) found that working memory capacity was a strong predictor of working memory updating, although some component processes, in particular, substitution skills, were independent of working memory capacity. In our study, we can assume that the predictive power of working memory updating measures may rely heavily on common working memory capacity functions, measured through the IF task (digit span). If the lower order working memory skills are compromised, then these will impact the higher order memory-related EF components required in the sport context. Hence, the higher order cognitive skills assessed by the EF updating task may make an independent contribution to predict how adequately athletes are able to perform on the sporting field.

To summarise, WM update seems to be a crucial and relevant skill to assess in the context of elite ID-sport performance. Although the task included in this study was feasible, as all participants with ID were able to understand and perform it correctly, the task will need some further considerations before it can effectively be included in the Sport Intelligence test battery. For instance, some of the practical parameters (culture-free and non-verbal) are not entirely fulfilled for the use in an international context. As a possible alternative, a non-verbal version including a set of pictures/objects could be developed, or other non-verbal alternatives like the simplified N-back task described by Karatekin, Marcus, and Couperus (2007) for the use in 10 year old children could be considered.

Task switching, or **set-shifting,** is an EF that involves the ability to shift attention between different tasks, mostly unconsciously. Set-shifting allows a person to rapidly and efficiently adapt to different situations, which is a crucial determinant of optimal sport performance. In many sports, the ability to perform well under various circumstances is crucial, for example when various opponents can be encountered (e.g., team sports) or when the opponent applies a variety of strategies (e.g., racket sports), or when different weather conditions can be encountered (e.g., cycling, skiing).

Set-shifting capacity of people with Down Syndrome (DS) and ID has been demonstrated as potentially compromised by Lanfranchi et al. (2010), using the Rule Shift Card Test and Modified Card Sorting Test. In our own study we observed that the participants with ID needed significantly more time to complete the colour trail tasks; however, the set-shifting interference score was not different between the groups. This result needs to be interpreted with caution, as there was a relatively high number of participants with ID in the non-athlete group (n=6) who were unable to perform this task, because they were unable to count to 25. For future research and inclusion in the Sport Intelligence Test, it will be necessary to select another type of set-shifting task in which no numerical literacy is required. Comparing our own results with findings by other authors also needs to take into account the different phenotypes of the participant sample, e.g., DS. Different phenotypes can produce distinct EF profiles, as shown by Costanzo et al. (2013) who demonstrated that participants with DS were poor in verbal and visual-spatial shifting, verbal aspects of memory and inhibition, whereas those with Williams syndrome were poor in planning, but not shifting. In our own study we only recruited people with ID without specific syndromes, as that was one of the exclusion criteria; hence, no fully compatible comparison can be made with previous literature.

To summarise, we are unable to conclude based on the results of this study that set-shifting is impaired in the general ID-population, although we have an indication that it might be the case, and it is worth further investigation. In search for a better alternative for future studies, card sorting tasks (Shields et al., 2020; Walley & Donaldson, 2005) or visual-spatial shifting tasks without any literal or numerical component such as the Color-Shape task described by Miyake, Emerson, Padilla, and Ahn (2004) could be relevant options. Given research from mainstream sports' literature we can expect that the performance of athletes with ID might be impacted upon deleteriously by their decreased set-shifting capacity, but more research is needed.

Intelligence versus EF

Over the last few decades, the conceptualisation of EF and intelligence, being two of the most complex cognitive processes, has received a lot of attention in literature (Duggan & Garcia-Barrera, 2015; Friedman & Miyake, 2017; Salthouse, 2005). EF is a challenging topic to define and to study, and there is ongoing debate on the unity versus diversity question, i.e., do different EF's correlate and load on a common underlying ability (unity) or are they fully distinguishable (diversity). Further adding to this complexity is the possibility of evolving relationship between EF's as a result of neurocognitive development (Brydges et al., 2012). Similar efforts in distinguishing the psychometric components involved in the structure of intelligence have produced the distinction between the two main core factors loading to g or general intelligence, that is, fluid intelligence (i.e., the ability to solve novel reasoning problems) and crystallized intelligence (i.e., the ability to apply acquired knowledge). The majority of papers on this topic state that EF does not fully coincides with IQ, but it is also stated that EF's coincide more with the fluid intelligence compared to the crystallized intelligence (Duggan & Garcia-Barrera, 2015).

In this context, our own study revealed a stronger association between EF and intelligence in people with ID compared to the population of people without ID. These differences in strength of the association between people with and without ID are interesting findings, and to the authors' knowledge, not demonstrated yet in previous research. It seems that a larger portion of the explained variance in EF skills might be explained by the deficits in their more basic intellectual functioning skills. We can assume that fundamental cognitive components are by definition compromised in people with ID, due to the nature of their impairment, and hence, the higher order skills will also be compromised, with potential impact across several contexts of daily functioning, potentially including sports.

On the contrary, the stronger relation between EF and fluid intelligence versus crystallized intelligence was more apparent in people without ID, as there was a strong and significant relation between inhibition and working memory update on the one side and fluid intelligence (matrix reasoning) on the other side. No significant association between EF and crystallized intelligence (vocabulary) was found in people without ID. In people with ID, strong associations were found between all EF measures and fluid intelligence, and two of the three EF measures and crystallized intelligence.

Sport intelligence of athletes with ID

In this study we were trying to answer a practical applied problem which has significance in the context of international Paralympic Sport Classification, and also in terms of talent selection and training. For coaches working with athletes with ID it is important to be aware of how specific EF deficits might implicate their sport performance, and how they can help their athletes to overcome these. It is not unlikely that the sport practice itself might contribute to better EF, also in people with ID. However, our results don't actually support that assumption that athletes have better EFs. The power of our study was too small to draw meaningful conclusions regarding the effect of sport expertise on EF. Further research is necessary to gain more insight in the effect of sport expertise or sport training, and how it effectively impacts on cognitive performance. It maybe that individuals who have innate abilities in these areas are better athletes and rise to the top, or that training improves these abilities, or a combination of both. It might also be the case that different sports require different profiles of strength across the range of EF skills, and so be differentially impacted in terms of performance by deficits in EF. For example, a running event in athletics where each athlete's performance is contiguous requires constant monitoring and potential adjustment, compared to shot put in athletics where performance is sequential and therefore potentially less complex in this respect. Hence, whilst it is important to include generic tests of EF in the Sports intelligence test it is also important to look at the wider impact of interpersonal and intrapersonal factors on their importance for sport performance.

Strengths and limitations

To the authors' knowledge, our study was the first to investigate performance on various EF domains, and the strength of the relation between EF and intelligence in a unique sample of elite athletes with ID. This study contributes to the development of evidence-based classification systems for high performance athletes with ID. However, there are also some limitations that need to be acknowledged. The sample size was too small to detect meaningful differences across the four samples, and it was not possible to pool all athletes versus the non-athletes, as the differences between ID and non-ID subgroups were too large. For future research it will be necessary to recruit more athletes and sedentary controls to demonstrate the effect of sport expertise on EF in people with ID.

Another limitation is the above average IQ in the non-ID population, indicating that this sample might not be representative for the general population. This might be due to the measurement itself (IQ estimation based on short version of the WAIS), or due to the characteristics of the sample (large proportion of university students). -

Finally, this study was part of a larger study, so fatigue and loss of concentration might have impacted the performance of the participants.

Conclusion

To find the optimal EF tasks, or battery of EF task that meet all the conditions to be suitable for use with people with ID, many factors need to be considered. In this case, additional requirements are added, related to the international character and broader context of this study, making it almost an impossible task to find the most optimal set of tests. Nevertheless, we have shown with this study that the Flanker task is feasible to use in elite athletes with ID, and that their inhibition capacity is significantly impaired. Working memory shifting and updating are also important EF skills to assess in this context; however, better testing, culture-free alternatives need to be identified.

Finally, it is interesting to be aware that Intelligence and EF are more strongly related in individuals with ID, compared to control group without ID.

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Table Captions

Table 1

Participants' characteristics

	with intellectual disability			without intellectual disability			TOTAL
	athlete	novice	total	athlete	novice	total	
N	14	15	29	15	15	30	59
Gender, M/F	10/4	10/5	20/9	11/4	10/5	21/9	41/18
M age, years	23.6 (5.3)	26.3 (4.6)	25.5 (5.5)	22.4 (4.6)	24.2 (6.4)	23.8 (5.4)	
M IQ	64.4 (12.3)	60.5 (15.1)	62.4 (13.7)	117.9 (13.3)	116.5 (10.1)	117.2 (11.4)	
M weekly physical activity, hours	9.1 (7.0)	2.7 (0.9)	5.8 (5.8)	7.3 (3.2)	1.8 (0.9)	4.6 (3.6)	
M lifetime accumulated training hours*	2933.8 (2634.4)			2427.3 (1518.6)			

Figures in parentheses are standard deviations; *calculated by multiplying training hours/week, total years of training and 52.14 (weeks to years conversion factor)

Table 2: Differences in executive function and intellectual function measures between people with and without intellectual disability (ID)

Characteristics	ID (*n* = 29)	AB (*n* = 30)	T_y	*P*	**ξ**
Executive function					
Flanker	23.4 (8.9)	38.5 (3.2)	**T_y(21.8) = 9.01**	**< .001**	**.95**
Word Span	7.8 (4.2)	22.1 (4.8)	**T_y(32.3) = 12.5**	**< .001**	**.97**
Color Trails – interference	0.92 (0.52)	0.98 (0.38)	T_y(26.9) = 0.20	.841	.08
Color Trails – time1	60.5 (30.3)	25.7 (5.8)	**T_y(14.8) = 4.49**	**< .001**	**.76**
Color Trails – time2	108.3 (53.0)	49.7 (8.5)	**T_y(14.9) = 5.40**	**< .001**	**.84**
WAIS–III subscales					
Vocabulary	3.5 (3.2)	13.6 (2.5)	**T_y(29.8) = 15.44**	**< .001**	**.92**
Symbol Substitution	3.9 (2.7)	11.5 (2.5)	**T_y(35.0) = 11.01**	**< .001**	**.90**
Matrix Reasoning	3.4 (2.5)	11.6 (2.0)	**T_y(33.9) = 13.09**	**< .001**	**.94**
Digit Span	5.1 (2.7)	13.0 (2.6)	**T_y(35.0) = 11.36**	**< .001**	**.88**

Table 3: Spearman rho correlations between executive function and intelligence measures in people with intellectual disability (ID).

	1	2	3	4	5	6	7	8	9	10
1. IQ	1.00									
2. Flanker[a]	.83**									
3. Word Span	.62**	.48*								
4. CT – interference[b]	.07	.16	.20							
5. CT – time1[c]	.54**	.75**	.41*	.59**						
6. CT – time2[b]	.40	.65**	.22	.06	.78**					
7. Vocabulary	.82**	.56**	.49*	.11	.30	.13				
8. Symbol substitution	.78**	.76**	.42*	.12	.60**	.59**	.47*			
9. Matrix reasoning	.70**	.55**	.48**	.17	.64**	.53**	.49**	.52**		
10. Digit span	.92**	.81**	.66**	–.14	.39	.32	.70**	.68**	.54**	1.00

[a] n = 28; [b] n = 23; [c] n = 25; * $p < .05$, ** $p < .01$, CT = Color Trails

Table 4: Spearman rho correlations between executive function and intelligence measures in people without intellectual disability (ID).

	1	2	3	4	5	6	7	8	9	10
1. IQ	1.00									
2. Flanker	.42*									
3. Word Span	.43*	–.04								
4. CT – interference	–.05	–.10	–.13							
5. CT – time1	.16	.31	–.10	.57**						
6. CT – time2	.34	.43*	.01	–.15	.64**					
7. Vocabulary	.72**	.11	.38	.25	.12	.08				
8. Symbol substitution	.22	.37*	–.01	–.25	.14	.38*	–.20			
9. Matrix reasoning	.75**	.37*	.48**	.15	.24	.31	.57**	.11		
10. Digit span	.68**	.29	.20	–.19	0	.18	.33	–.12	.26	1.00

* p < .05, ** p < .01, CT = color trails