EUJAPA

Article

Exploring the associations between physical fitness components and physical activity during gameplay in Special Olympics Unified Cup athletes

Franziska Loetzner [1,*], Leah R. Ketcheson [1], Michael VanNostrand [2], and E. Andrew Pitchford [3]

Received: 13th November 2024; Accepted: 20th August 2025; Published: 3rd August 2026

Abstract: Special Olympics provides health and sport opportunities to more than 4 million individuals with intellectual and developmental disabilities. Participation in physical activity can promote components of physical fitness in individuals with intellectual and developmental disabilities. Health-related physical fitness is closely associated with physical activity, yet individuals with disabilities are less likely to meet physical activity recommendations than the general public. The objective of this study was to examine the associations between physical fitness and physical activity during gameplay among Special Olympics athletes who participated in the 2022 Unified Cup in Detroit, Michigan. On-field physical activity and physical fitness data were collected from 70 Special Olympics athletes (male = 34; female = 36) during group-stage gameplay at the 2022 Unified Cup. Adequate or "healthy" performance on physical fitness components ranged from 47% to 97%. Associations between on-field physical activity and components of physical fitness were observed for hamstring flexibility, handgrip strength, blood pressure, and weight status. The strongest association observed was between on-field physical activity and athlete sex; thus, all analyses were conducted for the full sample and stratified by sex. These findings highlight the varying levels of physical fitness in Special Olympics athletes and suggest that several fitness components may relate to soccer gameplay. Findings should be utilized to reassess measurements and physical fitness evaluation in Healthy Athletes Screenings at Special Olympics events.

Keywords: intellectual and developmental disabilities; health screenings; flexibility; grip strength; energy expenditure

Introduction

Elite-level sports are a complex skill-based phenomenon. For skilled performance at this level, athletes must exhibit high levels of physical fitness and understand psychological factors, player technique, and team tactics (Gould et al., 1999). The most popular sport in the world, often seen played at an elite level, is soccer (a.k.a., football; Murray & Murray, 1998). Its popularity can be attributed to four aspects: (1) soccer has relatively simple rules, (2) little equipment is needed to play, (3) it is accessible across the world, and (4) many believe that soccer is a safer sport than other team sports (Metzl & Micheli, 1998).

Much like its global popularity, soccer is also the most popular sport within Special Olympics (Special Olympics, 2022). With more than 30 Olympic-style sports, Special Olympics provides physical activity (PA) and sport opportunities to more than 4 million individuals with intellectual or developmental disabilities (IDD) globally at various levels, spanning from recreational to elite competitions (Special Olympics, n.d.).

Additionally, Special Olympics offers free comprehensive health screenings through its Healthy Athletes Screenings (HAS) initiative. To date, HAS represents the largest international database of health among individuals with IDD (Lloyd et al., 2018). Special Olympics has conducted over 1.4 million health screenings in over 128 countries (Corbin & Holder, 2016). HAS aims to improve the quality of life and long-term health of Special Olympics athletes by promoting healthy behaviours, conducting free health screenings, and making appropriate medical referrals through eight unique disciplines. Two of the disciplines, Health Promotion (Prevention and Nutrition) and FUNfitness (Physical Therapy), give a critical lens into the physical fitness of Special Olympics athletes.

However, PA and sports participation are known to decline as children age into adolescence and adulthood (Corder et al., 2019; Deng & Fan, 2022). Concerningly, children, adolescents, and adults with IDD have low levels of physical activity (Einarsson et al., 2016; Frey et al., 2008). Leading health organizations continue to stress the importance of participation in health-enhancing PA (Centers for Disease Control and Prevention [CDC], 2019). Engaging in health-enhancing PA is important for overall well-being. It provides social, psychological, and physical benefits, including improved mood, reduced stress, lower levels of depression and anxiety, enhanced memory, as well as a decreased risk of cardiovascular disease and osteoporosis (CDC, 2019). The CDC reports that by following their recommendations of getting at least 60 minutes of moderate-to-vigorous PA daily, children, youth, and adolescents expect to see improvements in some components of physical fitness (CDC, 2019). Specifically, health-related physical fitness represents the components of physical fitness that demonstrate a relationship with good health (Caspersen et al., 1985).

There is a growing body of literature using Special Olympics HAS data to understand physical fitness among individuals with IDD, but this database remains underutilized (Lloyd et al., 2018). For example, multiple reports with international HAS data document high rates of overweight and obesity among athletes (Lloyd et al., 2012; Lloyd et al., 2018; Foley et al., 2014) and poor performance on tests of physical fitness among Special Olympics athletes (Cleveringa et al., 2022; Temple et al., 2022; Santarossa et al., 2017; Oskarsson et al., 2023). Despite these findings highlighting health challenges among these athletes, little is known about their physical fitness levels in relation to PA performance during Special Olympics competition.

There is a long history of research examining relationships between physical fitness and on-field PA, namely running performance, in both youth and professional soccer players (see Aquino et al., 2020). While there are conflicting reports regarding correlations between physical fitness and in-game running among athletes without disabilities (Aquino et al., 2020), recent research on 7-a-side soccer for athletes with cerebral palsy has demonstrated significant relationships (Pena-Gonzelez et al., 2024). To our knowledge, these relationships have not been examined within soccer competition for athletes with IDD.

With soccer being the most widely played sport in Special Olympics, the 2022 Unified Cup, an international Special Olympics soccer competition, provided a structured and competitive opportunity to examine the associations between physical fitness and on-field PA among elite-level athletes from around the world. Special Olympics competitions are offered in various playing levels, from basic skills competitions to international elite-level tournaments. Elite-level Special Olympics soccer, like the Unified Cup, differs from recreational play due to its higher intensity, training requirements, and structured competition modeled after the FIFA World Cup. Examining the on-field PA of athletes may offer insights into the actual workload experienced during gameplay. By understanding and quantifying on-field PA, coaches, programs, and teams can better grasp the physical demands placed on athletes during competition. This information can assist in developing training plans and practices to enhance athlete health and fitness in people with IDD more effectively.

Objective

The objective of this study was to examine the associations between physical fitness components and on-field PA in elite-level Special Olympics athletes who participated in the men’s and women’s tournaments of the 2022 Special Olympics Unified Cup. As aspects of physical fitness may be related to the physiological performance of gameplay for athletes with IDD, understanding these associations has the potential to influence training strategies and health promotion approaches within Special Olympics.

Materials and Methods

Setting

This study was conducted during the group stage of gameplay at the 2022 Unified Cup in Detroit, Michigan. The Unified Cup falls under the Special Olympics Unified Sports initiative, where athletes with IDD train and compete on the same team as a Unified partner without a disability; thus, teams consist of a combination of athletes and partners. Separate tournaments were held for women and men, mirroring the FIFA World Cup structure. The women's tournament consisted of 12 teams divided into three groups, with matches lasting 40 minutes, played in a 7-on-7 format on a smaller field. The men's tournament consisted of 10 teams split into two groups. They played for 60 minutes in an 11-on-11 format on a full-sized field. HAS screenings were held on-site at the tournament. Athletes and partners arrived at HAS with their teams and were encouraged to attend all eight disciplines of HAS. They received a sports-related incentive, provided by Special Olympics, upon completion of all disciplines.

Participants

The 2022 Unified Cup hosted a grand total of 291 players, including 161 Special Olympics athletes and 130 Unified partners, from 22 national teams across the men’s and women’s tournaments. Of the 161 athletes, 90 were male and 71 were female. A total of 102 athletes (63%), including 54 males and 48 females, consented to participate in the research study and wore accelerometers during gameplay. All athletes and partners had the opportunity to participate in the HAS and health education activities.

To be eligible for analysis within this study, athletes needed to: (1) compete in at least one game as a field player (goaltenders were excluded) with PA monitoring; (2) complete a weight measurement through HAS for use in the energy expenditure equation; and (3) complete at least one of the physical fitness tests through HAS. A sample of 70 athletes met these criteria.

The Special Olympics athletes in this study are considered to be elite-level athletes, as the Unified Cup was a high-level international competition within Special Olympics. The athletes who participate in this tournament generally undergo rigorous training and earn their spot in this competition through success in regional and/or national Special Olympics competitions (e.g., USA games, Eurasia games). While the definition of “elite” is in the context of Special Olympics and may differ from traditional sports settings, the Unified Cup serves as a proxy for advanced skill development and competitive experiences among athletes with IDD.

Participating in this study had no impact on athlete participation in the Unified Cup tournament. Although every player and team in the Unified Cup were invited to participate in this study, only participants who provided informed consent and assent were included in the study. Parents or guardians provided informed consent during registration for the Unified Cup prior to the tournament, and each athlete provided additional in-person assent on-site before participating in any research activities. Every team had an English-speaking coach, and interpreters were available to support participants and families who did not speak English. All research involving human subjects was subject to review and approval by the Institutional Review Board (IRB) at Wayne State University and Special Olympics.

Variables and Measurement

Physical Fitness

Components of physical fitness were collected through athlete participation in the Health Promotion and FUNfitness disciplines of HAS. Body composition was measured via body mass index (BMI) at Health Promotion with an additional measure of blood pressure. The authors note that BMI is not an accurate measure of body composition; however, using BMI as a measure of body composition in Special Olympics athletes is consistent with past literature (Baran et al., 2013; Gimunová et al., 2019). Flexibility, muscular strength, muscular endurance, and cardiorespiratory fitness were measured via modified Thomas test (hip flexibility), ankle dorsiflexion (calf flexibility), supine passive knee extension (hamstring flexibility), modified Apley's test (shoulder flexibility), grip strength, push-up hold, timed sit-to-stand, timed partial sit-up, and a 2-minute step test at FUNfitness. Health experts consulting for Special Olympics selected, modified, and designed these tests for HAS. These tests may differ from their traditional clinical counterparts to make them more accessible to athletes. Basic instructions given to the athletes, measurement tools, and number of trials can be found in Table 1. For more details on how measurements were completed and details on validity and reliability (if available), see the Special Olympics clinical director manuals for Health Promotion and FUNfitness available online via the Special Olympics HAS page (Special Olympics, 2023a, 2023b).

All raw measurements were collected via Special Olympics' data collection system and were uploaded to the Special Olympics database after HAS. The raw data were sent to the research team for data analysis. Using "need for education" cutoff points outlined in the Special Olympics clinical director manuals, athletes were placed into healthy and unhealthy categories based on their raw scores for each measure. A score that is flagged as "need for education" is a score that is in a critical zone and represents an unhealthy status as determined by Special Olympics. These scores and values can be seen in Table 1. All other scores were considered healthy.

Physical Activity

To objectively measure PA during gameplay, ActiGraph wGT3X+BT accelerometers (Pensacola, FL, USA) were used. ActiGraph accelerometers were worn above the right hip from warm-up to post-game and measured accelerations at a 100 Hz sampling rate. Time on the field was tracked through manual recording of substitutions and game duration. Post-match, data from the monitors were extracted using ActiLife version 6.13.4 software (Pensacola, FL, USA), aggregated in 1-second epochs, and processed using validated cutpoints based on triaxial vector magnitude (VM) counts (Sasaki et al., 2011), with non-game wear time excluded. Non-game wear time included warm-up, halftime, sideline, goalkeeping, and additional periods before and after the game. The game clock was synchronized with the accelerometer's internal timer to track these periods. Research assistants used a game log to track gameplay time for each participating team. The log included data on when the monitor was placed on the player, warm-up duration, game start time, on-field and goalie periods, sideline periods, halftime duration, match end time, and when the monitor was removed. The total gameplay time was calculated by summing the remaining time to the nearest hundredth of a second. Gameplay time as a goalkeeper was excluded due to the stationary nature of the position.

Table 1. *FUNfitness and health promotion measures*

Measure	Directions	Trials	Measurement	"Need for Education" value
FUNfitness measures				
Push-up hold	Sit in chair, push up using armrests, hold position as long as possible. Timer stops when position is lost.	1	Time (seconds)	<5 sec
Sit to stand	Sit with feet flat, stand and sit as fast as possible for 10 reps.	1	Time (seconds)	>20 sec or <10 reps
Partial sit-up	Lie on back, knees bent, arms forward. Perform as many correct sit-ups as possible in 1 min.	1	Repetitions	<25 reps
2-min step test	Stand next to a wall, raise knee to marked midpoint between knee and hip, repeat quickly for 2 min. Heart Rate (HR) Recovery is the difference between the post-exercise HR and the 2-min post-exercise HR.	1	Steps counted, HR recovery	HR Recovery >14 sec
Grip strength	Stand, grip dynamometer, squeeze as hard as possible. Repeat 3 times per arm.	3 per arm	Force (kg)	10th percentile
Shoulder flexibility	Reach one arm behind head, the other behind waist, try to touch fingers. Measure gap if fingers do not touch.	1 per side	Distance (cm)	-16 to -50 cm
Hip flexibility	Lie on back, hold one knee at 90°, lower other leg toward table. Measure thigh-table angle.	1 per leg	Angle (degrees)	< -10°
Calf flexibility	Lie on back, legs straight, flex foot upward. Measure ankle angle with goniometer.	1 per side	Angle (degrees)	<+5°
Hamstring flexibility	Lie on back, flex one hip and knee to 90°, straighten knee as far as possible. Measure knee angle.	1 per side	Angle (degrees)	-15° to -90°
Health promotion measures				
BMI	Remove shoes, measure weight on scale and height on stadiometer. Calculate BMI (weight/height²).	1	kg/m²	Underweight <18.5, Obese >30
Blood pressure	Sit, rest arm on table, place cuff on upper arm, start electronic reading. Repeat on other arm. Pulse Pressure can be calculated from blood pressure using: Pulse pressure = systolic blood pressure − diastolic blood pressure.	1 per arm	Systolic/Diastolic (mmHg)	High >60, Low <39.9

Note. Adapted from the Special Olympics Clinical Director Manuals for FUNfitness and Health Promotion. These measures were developed by Special Olympics International to be efficiently used within Healthy Athlete Screenings. Measures may have been modified and adapted for or by Special Olympics from standardized assessments.

Energy Expenditure

PA data were converted to energy expenditure for use in analyses. Most accelerometry data are used to quantify the minutes spent in different PA intensity levels (e.g., moderate, vigorous) based on cutpoints (Sasaki et al., 2011). However, these categories are difficult to interpret across a game as a single measure. Energy expenditure in kilocalories (kcal) represented a continuous measure of on-field PA that would be more interpretable than unitless VM counts. Accelerometry data from gameplay were converted to an estimate of kcal expended with the ActiLife software and Freedson VM3 combination equation (Freedson et al., 1998, 2011; Sasaki et al., 2011), based on triaxial VM counts. The Freedson VM3 combination equation combines the Freedson VM3 formula with the Williams Work-Energy equation when VM counts per minute were greater than or less than, 2453, respectively, to calculate energy expenditure in kcal per minute (ActiGraph, 2018). Both equations account for the body mass of the individual. Previous studies in adults have found this approach to estimate energy expenditure within 10% equivalence compared to indirect calorimetry (Bai et al., 2016). Kcals were averaged across available games for each athlete and presented as average kcals/game.

Statistical Methods

All demographic data is presented as mean (standard deviation) when data were continuous, and frequency (%) when data were categorical. Associations between PA during gameplay and components of physical fitness were examined with point-biserial correlation to account for the continuous and categorical combination of data. Associations between PA and age were calculated with Pearson product-moment correlation. All analyses used an alpha of 0.05, pairwise deletion for missing data, and were repeated for the full sample and separately by sex. Statistical analyses were performed in SPSS version 29.0 (IBM Corp., 2024).

Results

The sample of 70 Special Olympics athletes with IDD included 34 males (49%) and 36 females (51%). Athletes were, on average, 18.30 ± 1.78 years of age (males: 18.74 ± 1.73; females: 17.89 ± 1.75). Athlete PA during gameplay was 226.43 ± 97.19 kcal/game (males: 291.84 ± 91.26; females: 164.66 ± 51.84). Performance on components of physical fitness, based on HAS criteria, is presented in Table 2. In all fitness components, except for calf flexibility, the majority of athletes produced adequate scores (>50%) based on the pre-established criteria.

Table 2. *Special Olympics athlete performance on physical fitness components*

Fitness component	Total			Male			Female		
	f	%	N	f	%	N	f	%	N
Flexibility									
Hamstring	21	68%	31	7	44%	16	14	93%	15
Calf	15	47%	32	7	41%	17	8	53%	15
Hip	30	97%	31	16	100%	16	14	93%	15
Shoulder	27	84%	32	14	82%	17	13	87%	15
Muscular endurance									
Timed sit-to-stand	21	72%	29	11	79%	14	10	67%	15
Partial sit up	22	69%	32	12	71%	17	10	67%	15
Push up	31	97%	32	17	100%	17	14	93%	15
Muscular strength									
Grip strength	18	62%	29	3	21%	14	15	100%	15
Aerobic fitness									
2-min step test	19	65%	29	12	80%	15	7	50%	14
Blood pressure									
High pulse pressure	20	29%	70	15	44%	34	5	14%	36
Normal pulse pressure	41	59%	70	17	50%	34	24	67%	36
Low pulse pressure	9	13%	70	2	6%	34	7	19%	36
Body composition									
Underweight	6	9%	70	3	9%	34	3	8%	36
Healthy weight	42	60%	70	23	68%	34	19	53%	36
Overweight	18	26%	70	8	24%	34	10	28%	36
Obese	4	6%	70	0	0%	34	4	11%	36

Note. Results are organized by total sample and male and female subsamples. The frequency (f) and proportion (%) with each physical fitness variable representing adequate (i.e. healthy) performance or group categorization (e.g., body composition, blood pressure). The sample size (N) for each variable is based on pairwise deletion.

Associations between kcal expended during gameplay and fitness components are presented in Table 3. The strongest association was between kcal/game and sex (r_{pb} = -.659, p < .001), in favor of male athletes. Due to this strong association, correlations are presented for the total sample and separated by sex. Four components of physical fitness had statistically significant associations with on-field PA. Adequate hamstring flexibility (r_{pb} = .442, p = .013) and handgrip strength (r_{pb} = .463, p = .011) had moderate, positive associations with kcals/game. Conversely, athletes with low pulse pressure (r_{pb} = -.252, p = .035) and underweight status (r_{pb} = -.286, p = .016) had weak, negative associations with kcal/game. Within male athletes, kcal/game were negatively associated with underweight status (r_{pb} = -.535, p = .001) but positively associated with overweight status (r_{pb} = .381, p = .026). No significant associations were observed among female athletes

Table 3. *Associations between gameplay PA and physical fitness components*

	kcals (avg/game)		
Variables	Total	Male	Female
Demographics			
Age (years) [a]	.094	-.119	-.042
Sex	-.659**	‡	‡
Flexibility			
Hamstring	.442*	.127	.124
Calf	.026	-.245	.243
Hip	-.215	‡	-.265
Shoulder	.124	.213	-.103
Muscular endurance			
Timed sit-to-stand	.011	.057	.280
Partial sit up	-.182	-.158	-.355
Push up	-.217	‡	-.265
Muscular strength			
Grip strength	.463*	-.290	‡
Aerobic fitness			
2-min step test	-.206	.079	-.045
Blood pressure			
High pulse pressure	.231	-.022	.104
Normal pulse pressure	-.041	.073	.142
Low pulse pressure	-.252*	-.109	-.260
Body composition			
Underweight	-.286*	-.535**	-.173
Healthy weight	.092	-.021	.004
Overweight	.191	.381*	.198
Obese	-.208	‡	-.136

*Note. Correlations of kcal (avg/game) with each dichotomous variable reflecting low performance on each fitness test are presented as point-biserial correlations (r_{pb}), unless otherwise noted. [a] Pearson product moment correlation (r). ‡ Correlation could not be computed as the variable is constant (i.e., 0% or 100%). * p < .05, ** p < .01*

Discussion

This study aimed to explore associations between physical fitness and gameplay PA in Special Olympics athletes during group play at the 2022 Unified Cup. In the full sample, significant associations were present for three of the five components of physical fitness: flexibility, muscular strength, and body composition, as well as blood pressure. For male athletes, significant associations were seen in body composition. No significant associations were identified for female athletes.

Sex differences in health and physical activity (PA) have been widely studied. Among adults, females are typically 6–10% less physically active than males (Eaton, 1986). However, research suggests that low to moderate-intensity PA provides greater benefits for females in preventing cardiovascular disease and diabetes compared to males (Sattelmair et al., 2011). This aligns with the "male-female health-survival paradox," which highlights that while women tend to live longer, they often experience poorer health (Alberts et al., 2014). Among individuals with IDD, adult females face increased risks for conditions such as nutritional deficiencies, neurologic diseases, psychiatric disorders, and sleep issues (DaWalt et al., 2021). However, research on gender-specific differences in health and PA among adults with IDD remains inconclusive. Some studies report disparities (Van de Vliet et al., 2006), while others do not (Einarsson et al., 2015).

Despite extensive research in neurotypical populations, the impact of sex on PA in adults with IDD remains unclear. However, our findings indicate a significant association between sex and gameplay energy expenditure, favoring male players. Similarly, in professional soccer, female players exhibit significantly lower endurance-related physical capabilities than their male counterparts (Cardoso de Araújo et al., 2020). However, another study found no significant differences in endurance fitness performance scores, such as shuttle runs, between high-level male and female college soccer players (Lockie et al., 2018). Nevertheless, in the context of the Unified Cup, it may be difficult to conceptualize sex differences as there was a difference in playtime and field size between the men's and women's tournament. While known sex differences could explain our results, we must acknowledge that the difference in game structure could have impacted kcal/game.

BMI relates uniquely to PA. Generally, obesity results from an imbalance of energy expenditure and intake (Romieu et al., 2017). In the general population, energy expenditure is usually higher in obese groups (Elbelt et al., 2010; Delany et al., 2013), yet obese individuals often exhibit lower PA levels (Hansen et al., 2013). The main determinants of daily energy expenditure are body size and PA (Schoeller et al., 1982). Individuals with IDD are more likely to be obese and have lower PA, possibly moving less during gameplay. While PA can be prescribed to combat obesity, the adverse effects of excess body fat are evident. Individuals who are obese have an increased risk for mortality, cardiovascular disease, liver disease, and type 2 diabetes (Fabbrini et al., 2010). However, underweight athletes in the Unified Cup expended fewer calories during gameplay. This may be due to reduced energy availability, as being underweight results from decreased energy intake. With less stored energy, these athletes might have a lower capacity to move during gameplay. Notably, caution has been expressed regarding BMI as a measure of body composition in elite athletes (Nevill et al., 2006). Often, elite athletes may fall into the overweight category (Provencher et al., 2018). BMI only considers body mass and does not reflect its composition. In these Special Olympics athletes, BMI may not be an accurate indicator of "healthy" body composition.

Hamstring flexibility is widely studied in soccer players, specifically at the elite and college level. Hamstring-related injuries are common in soccer, making up for approximately 16% of injuries (Petersen et al., 2010). Soccer is a combination of running, agility, and repetitive kicking, which puts stress on the groin, hamstring, and hips. Particularly, hamstring injuries occur during rapid speed increases or decreases while running and while jumping (Goldman & Jones, 2011). Soccer players who have experienced hamstring-related injuries have significantly lower levels of hamstring flexibility (Witvrouw et al., 2003). In individuals with IDD, having low muscle tone is an impairment often associated with their disability (Gabis et al., 2021), possibly resulting in an increase in flexibility. Hamstring flexibility is generally considered critical in soccer players to prevent injury to the hamstring and quadriceps muscles (Witvrouw et al., 2003). In athletes participating in the Unified Cup, there was a positive association between high hamstring flexibility and on-field PA. Special Olympics stresses the importance of integrating dynamic and static stretching in their sports. While specifics of each team's practices are not known, a 10-week soccer training example from Special Olympics emphasizes hamstring stretching, along with the groin, as key muscle groups for coaches to target in their soccer practices (Special Olympics, 2012).

Healthy grip strength (muscular strength) was associated with higher levels of on-field PA. Grip strength is known to be a critical biomarker in assessing health. Healthy or high grip strength scores have been associated with better brain health, higher levels of health-related quality of life, reduced risk of cardiovascular health issues, and longevity (Carson et al., 2018; Sayer et al., 2006; Leong et al., 2015).

The association between low pulse pressure and energy expenditure is relatively unknown. In 2000, Wareham and colleagues found that low habitual energy expenditure is related to increased blood pressure. In general, high pulse pressure (high blood pressure, i.e., hypertension) is the most common cardiovascular disorder in athletes (Leddy & Izzo, 2009). Low pulse pressure indicates reduced cardiac output. Therefore, the association seen in elite-level athletes with IDD in this study is difficult to explain.

Limitations

There are limitations to this study. Most notable is the participation methodology between FUNfitness and Health Promotion at HAS. The differences in the number of athletes who attended each discipline at the Unified Cup are concerning. Despite the best efforts from research staff, it was difficult to target each possible participant at such a large event and encourage participation in both disciplines when completion of all HAS disciplines is not required by Special Olympics. Secondly, not all athletes who participated in HAS enrolled in the PA monitor study. These two factors were responsible for the shrinking number of athletes in each stage of analysis, resulting in the exploratory nature of this study. Further, the data could not be separated by sex for analysis due to the small sample size and the number of predictors in the model, leading gender to be the primary driver.

The measures of physical fitness used in this study were created for Special Olympics Healthy Athletes Screenings. Limited information is available regarding the clinometric properties of these measures. Specifically, the validity and reliability of each measure used within the HAS screenings is not available to be reported in this manuscript. Although a clinical director manual exists for practitioners performing the Health Promotion and FUNfitness screening, the psychometric properties specifically within the HAS context have not been thoroughly examined and therefore cannot be reported. While using standardized, validated, and more reliable measures would have been preferred, the measures used were dictated by the Healthy Athlete's protocol developed by Special Olympics International. The fitness data used in this study are housed in the Healthy Athletes Database making measurement adjustments not possible.

Furthermore, the measures and cutoff points for "need for education", or critical scores, within Health Promotion and FUNfitness were developed for HAS in 2000 and 1999, with the most recent revision of measures occurring in 2006. While the manuals for the clinical directors have been updated as recently as 2023, the measures and methods have remained unchanged for nearly 20 years. Research in disability sport, adapted PA, and Special Olympics is a growing field with new studies highlighting best practices for measurement each year. It is critical to consider the needs of individuals with IDD when developing physical fitness assessments. The measures used in this study may not provide a clear look into the current fitness status of elite-level athletes with IDD due to the use of inapplicable or outdated measures. For instance, the 2 Minute Step Test used in the HAS protocol was developed for individuals 65 and older (Rikli, 2013), and the use of BMI as a measure of body composition is generally considered not to be best practice (Buss, 2014) nor is it a true measure of "body composition". An alternative, like a 7-site skinfold measure, may be more applicable, but would also be much more invasive for athletes. Descriptives of HAS variables (Table 2) for this population indicate a range of 47% to 97% of all athletes falling into healthy categories for components of fitness (i.e. flexibility, muscular endurance, muscular strength, aerobic fitness). For an elite level athlete, a narrower and consistent range of healthy scores would be expected.

There are also limitations to the use of ActiGraph and the subsequent cutpoints and equations used to estimate energy expenditure. While these cutpoints and equations have been extensively validated, there remain error in any estimation procedure. Moreover, it is not clear how accurate these methods are for individuals with intellectual and developmental disabilities, despite being used in previous physical activity studies in this population (Leung et al., 2017). The primary limitation is the risk of underestimation of energy expended among athletes with Down syndrome (Agiovlasitis et al., 2023). However, athlete diagnosis was not available through Special Olympics for this study.

Finally, as this study is cross-sectional in nature, the associations observed cannot infer a cause-and-effect relationship between physical fitness status and on-field PA. Future studies with longer durations or experimental designs are needed to better understand how changes in fitness and gameplay PA are connected among Special Olympics athletes. Ultimately, this study might not be generalizable to other athletes participating in Special Olympics due to skill level of athletes competing in the Unified Cup. Findings may only be applicable to athletes with IDD participating in a high level of sports play.

Future Directions

This study highlights the possible need to address changes to HAS methodology, including measures of physical fitness. Because data collected through HAS are entered into the Healthy Athletes Database, it is critical that the screening protocol includes reliable and valid measures that are appropriate and equitable for individuals with IDD.. Further, a replication of this study at a lower level of play, such as at a statewide or regional competition, may provide a more generalizable examination of the relationship between physical fitness and gameplay PA in a more typical (i.e., recreational) Special Olympics athlete.

Conclusions

In this exploratory study, PA during gameplay showed significant associations with several physical fitness components. Moderate, positive relationships were observed between kcal/game and both hamstring flexibility and handgrip strength. Low pulse pressure and underweight status were negatively associated with on-field PA. However, sex was the strongest predictor of gameplay PA. Among male athletes, underweight status was negatively associated with kcal/game, whereas overweight status showed a positive relationship. No significant associations were found among female athletes. Using kcal per game to examine on-field PA, this study provides a foundation for the physiological demands that Special Olympics athletes require at an elite level. However, results from this study indicate a need to re-explore appropriate measures of physical fitness within HAS.

Additionally, "need for education" groupings within the HAS database should be revisited or revised to better reflect the needs and abilities of athletes with IDD.

Perspectives

This study has three key practical implications.

1. Sex and specific physical fitness components are associated with physical activity during gameplay, particularly in male athletes.
2. Fitness tests used within Special Olympics' free health screenings should be updated using current best practices to appropriately address the fitness of individuals with intellectual and developmental disabilities.
3. Categories that indicate poor health and fitness derived from health and fitness testing at Special Olympics health screening events should be reassessed while considering the unique needs of individuals with intellectual or developmental disabilities.

Author affiliations:

[1] Division of Kinesiology, Health, and Sport Science, Wayne State University, 5101 John C Lodge Fwy, Detroit, MI, 48202; loetzner@wayne.edu, leah.ketcheson@wayne.edu

[2] Eugene Applebaum College of Pharmacy and Health Sciences, Wayne State University, 259 Mack Ave, Detroit, MI 48201; michael.vannostrand@wayne.edu

[3] College of Health, Oregon State University, 2520 SW Campus Way, Corvallis, OR 97331; andrew.pitchford@oregonstate.edu

* Correspondence: frloetz@iu.edu School of Health and Human Sciences, Indiana University Indianapolis, 901 W New York St, Indianapolis, IN 46202

Author Contributions: Franziska Loetzner, Ph.D.: Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, Writing – Original Draft, Visualization, Project Administration, and Writing – Review & Editing. Leah R. Ketcheson, Ph.D.: Supervision, Investigation, Project Administration, and Writing – Review & Editing. Michael VanNostrand, Ph.D.: Methodology, Formal Analysis, Writing – Original Draft, and Visualization. E. Andrew Pitchford, Ph.D.: Conceptualization, Methodology, Investigation, Data Curation, Writing – Review & Editing, and Supervision

Funding: This research received no external funding

Availability of data and materials: Some data that supports the findings of this study are openly available in Healthy Athletes Database at https://data.specialolympics.help/ reference number not available. Some data that supports the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical reasons.

Acknowledgments: Authors would like to acknowledge Special Olympics International and their support for this project.

Conflicts of Interest: Authors declare no conflict of interest

References

ActiGraph. (2018). *What is the difference among the energy expenditure algorithms?* https://actigraphcorp.force.com/support/s/article/What-is-the-difference-among-the-Energy-Expenditure-Algorithms

Agiovlasitis, S., Ballenger, B. K., Schultz, E. E., Du, Q., & Motl, R. W. (2023). Calibration of hip accelerometers for measuring physical activity and sedentary behaviours in adults with Down syndrome. *Journal of Intellectual Disability Research, 67*(2), 172–181. https://doi.org/10.1111/jir.13002

Aquino, R., Carling, C., Maia, J.A., Vieira, L.H., Wilson, R., Smith, N.M., Almeida, R.M., Gonçalves, L.G., Kalva-Filho, C.A., Garganta, J.M., & Puggina, E.F. (2020). Relationships between running demands in soccer match-play, anthropometric, and physical fitness characteristics: a systematic review. *International Journal of Performance Analysis in Sport, 20*(3), 534–555. https://doi.org/10.1080/24748668.2020.1746555

Alberts, S. C., Archie, E. A., Gesquiere, L. R., Altmann, J., Vaupel, J. W., & Christensen, K. (2014). The male-female health-survival paradox: a comparative perspective on sex differences in aging and mortality. *In Sociality, hierarchy, health: comparative biodemography: a collection of papers*. National Academies Press (US).

Bai, Y., Welk, G. J., Nam, Y. H., Lee, J. A., Lee, J. M., Kim, Y., Meier, N. F., & Dixon, P. M. (2016). Comparison of consumer and research monitors under semistructured settings. *Medicine and Science in Sports and Exercise, 48*(1), 151–158. https://doi.org/10.1249/MSS.0000000000000727

Baran, F., Aktop, A., Özer, D., Nalbant, S., Ağlamış, E., Barak, S., & Hutzler, Y. (2013). The effects of a Special Olympics Unified Sports Soccer training program on anthropometry, physical fitness and skilled performance in Special Olympics soccer athletes and non-disabled partners. *Research in Developmental Disabilities*, 34(1), 695–709. https://doi.org/10.1016/j.ridd.2012.10.003

Buss, J. (2014). Limitations of body mass index to assess body fat. *Workplace Health & Safety*, 62(6), 264–264. https://doi.org/10.3928/21650799-20140514-04

Cardoso de Araújo, M., Baumgart, C., Jansen, C. T., Freiwald, J., & Hoppe, M. W. (2020). Sex differences in physical capacities of German Bundesliga soccer players. *Journal of Strength and Conditioning Research*, *34*(8), 2329–2337. https://doi.org/10.1519/JSC.0000000000002662

Carson, R. G. (2018). Get A Grip: Individual variations in grip strength are a marker of brain health. *Neurobiology Of Aging, 71*, 189–222. https://doi.org/10.1016/J.Neurobiolaging.2018.07.023

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126.

Centers for Disease Control and Prevention. (2019). *Physical activity guidelines for Americans* (2nd ed.). Health.gov. https://Health.Gov/Healthypeople/Tools-Action/Browse-Evidence-Based-Resources/Physical-Activity-Guidelines-Americans-2nd-Edition

Cleveringa, M., & Pitchford, E. A. (2022). Low muscle strength, low bone mineral density, and high body mass index among adult Special Olympics athletes: A cross-sectional examination. *Adapted Physical Activity Quarterly, 40*(1), 19–37. https://doi.org/10.1123/apaq.2021-019 1

Corbin, S., & Holder, M. (2016). Special Olympics. In I. L. Rubin, J. Merrick, D. E. Greydanus, & D. R. Patel (Eds.), Health care for people with intellectual and developmental disabilities across the lifespan (pp. 2187–2195). *Springer International Publishing*. https://doi.org/10.1007/978-3-319-18096-0_165

Corder, K., Winpenny, E., Love, R., Brown, H. E., White, M., & Sluijs, E. V. (2019). Change in physical activity from adolescence to early adulthood: A systematic review and meta-analysis of longitudinal cohort studies. *British Journal of Sports Medicine*, *53*(8), 496–503. https://doi.org/10.1136/Bjsports-2016-097330

DaWalt, L. S., Taylor, J. L., Movaghar, A., Hong, J., Kim, B., Brilliant, M., & Mailick, M. R. (2021). Health profiles of adults with autism spectrum disorder: Differences between women and men. *Autism Research, 14*(9), 1896-1904. https://doi.org/10.1002/aur.2563

Delany, J. P., Kelley, D. E., Hames, K. C., Jakicic, J. M., & Goodpaster, B. H. (2013). High energy expenditure masks low physical activity in obesity. *International Journal of Obesity (2005), 37*(7), 1006–1011. https://doi.org/10.1038/Ijo.2012.172

Deng, Y., & Fan, A. (2022). Trends in sports participation in afromscents: Data from a large-scale sample in the US adolescents. *Frontiers in Public Health, 10*, 960098. https://doi.org/10.3389/Fpubh.2022.960098

Eaton, W. O., & Enns, L. R. (1986). Sex differences in human motor activity level. *Psychological Bulletin*, *100*(1), 19–28. https://doi.org/10.1037/0033-2909.100.1.19

Einarsson, I. Ó., Ólafsson, Á., Hinriksdóttir, G., Jóhannsson, E., Daly, D., & Arngrímsson, S. A. (2015). Differences in physical activity among youth with and without intellectual disability. *Medicine & Science in Sports & Exercise, 47*(2), 411-418. https://doi.org/10.1249/MSS.0000000000000412

Einarsson, I. Þ., Jóhannsson, E., Daly, D., & Arngrímsson, S. Á. (2016). Physical activity during school and after school among youth with and without intellectual disability. *Research in Developmental Disabilities, 56,* 60–70. https://doi.org/10.1016/j.ridd.2016.05.016

Einarsson, I. Ó., Ólafsson, Á., Hinriksdóttir, G., Jóhannsson, E., Daly, D., & Arngrímsson, S. Á. (2015). Differences in physical activity among youth with and without intellectual disability. *Medicine & Science in Sports & Exercise*, 47(2), 411–418. https://doi.org/10.1249/mss.0000000000000412

Elbelt, U., Schuetz, T., Hoffmann, I., Pirlich, M., Strasburger, C. J., & Lochs, H. (2010). Differences of energy expenditure and physical activity patterns in subjects with various degrees of obesity. *Clinical Nutrition, 29*(6), 766–772. https://doi.org/10.1016/J.Clnu.2010.05.003

Fabbrini, E., Sullivan, S., & Klein, S. (2010). Obesity and nonalcoholic fatty liver disease: Biochemical, metabolic, and clinical implications. *Hepatology, 51*(2), 679-689. https://doi.org/10.1002/Hep.23280

Foley, J. T., Lloyd, M., Vogl, D., & Temple, V. A. (2014). Obesity trends of 8-18 year old Special Olympians: 2005-2010. *Research in Developmental Disabilities, 35*(3), 705–710. https://doi.org/10.1016/j.ridd.2013.12.005

Freedson, P. S., Lyden, K., Kozey-Keadle, S., & Staudenmayer, J. (2011). Evaluation of artificial neural network algorithms for predicting METS and activity type from accelerometer data: Validation on an independent sample. *Journal of Applied Physiology, 111*(6), 1804-1812. https://doi.org/10.1152/Japplphysiol.00309.2011

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the computer science and applications, Inc. Accelerometer. *Medicine and Science in Sports and Exercise, 30*(5), 777-781. https://doi.org/10.1097/00005768-199805000-0002

Frey, G. C., Stanish, H. I., & Temple, V. A. (2008). Physical activity of youth with intellectual disability: review and research agenda. *Adapted Physical Activity Quarterly, 25*(2), 95–117. https://doi.org/10.1123/apaq.25.2.95

Gabis, L. V., Shaham, M., Leon Attia, O., Shefer, S., Rosenan, R., Gabis, T., & Daloya, M. (2021). The weak link: Hypotonia in infancy and autism early identification. *Frontiers in Neurology, 12*, 612674. https://doi.org/10.3389/Fneur.2021.612674

Gimunová, M., Válková, H., Kalina, T., & Vodička, T. (2019). The relationship between body composition and foot posture index in Special Olympics athletes. *Acta of Bioengineering and Biomechanics, 21*(4). https://doi.org/10.37190/ABB-01416-2019-02

Goldman, E. F., & Jones, D. E. (2011). Interventions for preventing hamstring injuries: a systematic review. *Physiotherapy*, *97*(2), 91–99. https://doi.org/10.1016/j.physio.2010.11.011

Gould, D., Guinan, D., Greenleaf, C., Medbery, R., & Peterson, K. (1999). Factors affecting Olympic performance: Perceptions of athletes and coaches from more and less successful teams. *The Sport Psychologist, 13*(4), 371–394. https://doi.org/10.1123/Tsp.13.4.37

Hansen, B. H., Holme, I., Anderssen, S. A., & Kolle, E. (2013). Patterns of objectively measured physical activity in normal weight, overweight, and obese individuals (20-85 Years): A cross-sectional study. Plos ONE*, 8*(1), E53044. https://doi.org/10.1371/Journal.Pone.0053044

IBM Corp. (2024). *IBM SPSS statistics for Windows* (Version 29.0) [Computer Software]. IBM Corp.

Leddy, J. J., & Izzo, J. (2009). Hypertension in athletes. *Journal of Clinical Hypertension*, *11*(4), 226–233. https://doi.org/10.1111/j.1751-7176.2009.00100.x

Leong, D. P., Teo, K. K., Rangarajan, S., Lopez-Jaramillo, P., Avezum, A., Jr, Orlandini, A., Seron, P., Ahmed, S. H., Rosengren, A., Kelishadi, R., Rahman, O., Swaminathan, S., Iqbal, R., Gupta, R., Lear, S. A., Oguz, A., Yusoff, K., Zatonska, K., Chifamba, J., Igumbor, E., … Prospective Urban Rural Epidemiology (PURE) Study investigators (2015). Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. *The Lancet, 386*(9990), 266-273. https://doi.org/10.1016/S0140-6736(14)62000-6

Leung, W., Siebert, E. A., & Yun, J. (2017). Measuring physical activity with accelerometers for individuals with intellectual disability: A systematic review. *Research in Developmental Disabilities, 67*, 60-70. http://doi.org/10.1016/j.ridd.2017.06.001

Lloyd, M., Foley, J. T., & Temple, V. A. (2018). Maximizing the use of Special Olympics International's Healthy Athletes database: A call to action. *Research in Developmental Disabilities, 73*, 58–66. https://doi.org/10.1016/j.ridd.2017.12.009

Lloyd, M., Temple, V. A., & Foley, J. T. (2012). International BMI comparison of children and youth with Intellectual Disabilities participating in Special Olympics. *Research In Developmental Disabilities, 33*(6), 1708–1714. https://doi.org/10.1016/J.Ridd.2012.04.014

Lockie, R. G., Moreno, M. R., Lazar, A., Orjalo, A. J., Giuliano, D. V., Risso, F. G., Davis, D. L., Crelling, J. B., Lockwood, J. R., & Jalilvand, F. (2018). The physical and athletic performance characteristics of Division I collegiate female soccer players by position. *The Journal of Strength & Conditioning Research, 32*(2), 334-343. https://doi.org/10.1519/JSC.0000000000001561

Metzl, J. D., & Micheli, L. J. (1998). Youth Soccer: An epidemiologic perspective. *Clinics In Sports Medicine, 17*(4), 663-673. https://doi.org/10.1016/S0278-5919(05)70110-1

Murray, B., & Murray, W. J. (1998). The world's game: A history of soccer. *University Of Illinois Press*.

Nevill, A. M., Stewart, A. D., Olds, T., & Holder, R. (2006). Relationship between adiposity and body size reveals limitations of BMI. *American Journal of Physical Anthropology, 129(*1), 151–156. https://doi.org/10.1002/ajpa.20262

Oskarsson, J., Fjellström, S., Hansen, E., & Ohlsson, M. (2023). Differences in Special Olympics athletes and non-athletes with intellectual disability: physical activity, strength and aerobic fitness. *European Journal of Adapted Physical Activity*, 16, Article 7. https://doi.org/10.5507/euj.2022.015

Peña-González, I., Henríquez, M., García-Hernández, J. J., & Moya-Ramón, M. (2024). Relationship between physical fitness parameters and match time motion performance in international footballers with cerebral palsy. *International Journal of Performance Analysis in Sport, 25*(1), 92-107. https://doi.org/10.1080/24748668.2024.2387905

Petersen, J., Thorborg, K., Nielsen, M. B., & Hölmich, P. (2010). Acute hamstring injuries in Danish elite football: a 12-month prospective registration study among 374 players. *Scandinavian Journal of Medicine & Science in Sports*, *20*(4), 588–592. https://doi.org/10.1111/j.1600-0838.2009.00995.x

Provencher, M. T., Chahla, J., Sanchez, G., Cinque, M. E., Kennedy, N. I., Whalen, J., Price, M. D., Moatshe, G., & Laprade, R. F. (2018). Body mass index versus body fat percentage in prospective National Football League athletes: Overestimation of obesity rate in athletes at the National Football League scouting combine. *Journal Of Strength and Conditioning Research, 32*(4), 1013–1019. https://doi.org/10.1519/Jsc.0000000000002449

Rikli, R. E., & Jones, C. J. (2013). Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *The Gerontologist, 53*(2), 255–267. https://doi.org/10.1093/geront/gns071

Romieu, I., Dossus, L., Barquera, S., Blottière, H. M., Franks, P. W., Gunter, M., Hwalla, N., Hursting, S. D., Leitzmann, M., Margetts, B., Nishida, C., Potischman, N., Seidell, J., Stepien, M., Wang, Y., Westerterp, K., Winichagoon, P., Wiseman, M., Willett, W. C., & IARC Working Group On Energy Balance And Obesity (2017). Energy balance and obesity: What are the main drivers?. *Cancer Causes & Control, 28*(3), 247–258. https://doi.org/10.1007/S10552-017-0869-Z

Santarossa, S., Temple, V. A., Rintala, P., Lloyd, M., DeMarco, B., & Foley, J.T. (2017). Muscular strength of adult Special Olympians by country economic status. *European Journal of Adapted Physical Activity, 10*(1), 10-16. https://doi.org/10.5507/euj.2017.002

Sasaki, J. E., John, D., & Freedson, P. S. (2011). Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport, 14*(5), 411–416. https://doi.org/10.1016/j.jsams.2011.04.003

Sattelmair, J., Pertman, J., Ding, E. L., Kohl, H. W., 3rd, Haskell, W., & Lee, I. M. (2011). Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation*, *124*(7), 789–795. https://doi.org/10.1161/CIRCULATIONAHA.110.010710

Sayer, A. A., Syddall, H. E., Martin, H. J., Dennison, E. M., Roberts, H. C., & Cooper, C. (2006). Is grip strength associated with health-related quality of life? Findings from the Hertfordshire cohort study. *Age and Ageing, 35*(4), 409–415. https://doi.org/10.1093/Ageing/Afl024
Schoeller, D. A., & Van Santen, E. (1982). Measurement of energy expenditure in humans by doubly labeled water method. *Journal Of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 53*(4), 955–959. https://doi.org/10.1152/Jappl.1982.53.4.955
Special Olympics. (2012). 10-week season plan for Special Olympics football (soccer). https://sonc.net/wp-content/uploads/2021/04/CSOA-Unit-2-10-Week-Season-Plan-Soccer.pdf
Special Olympics. (2022, November 3). *Football*. SpecialOlympics.org. https://www.specialolympics.org/what-we-do/sports/football
Special Olympics. (2023a). *FUNfitness manual*. Washington D.C.; Special Olympics.
Special Olympics. (2023b). *Health promotion manual*. Washington D.C.; Special Olympics.
Special Olympics. (n.d.). *Sports*. SpecialOlympics.org. https://www.specialolympics.org/what-we-do/sports
Temple, V. A., Rintala, P., Zeitz, S., Lloyd, M., & Foley, J. T. (2022). Age and sex-based differences in functional strength of adults participating in Special Olympics. *European Journal of Adapted Physical Activity*, 15, Article 1. https://doi.org/10.5507/euj.2021.009
Van de Vliet, P., Rintala, P., Fröjd, K., Verellen, J., Van Houtte, S., Daly, D. J., & Vanlandewijck, Y. C. (2006). Physical fitness profile of elite athletes with intellectual disability. *Scandinavian Journal of Medicine & Science in Sports*, 16(6), 417-425. https://doi.org/10.1111/j.1600-0838.2006.00539.x
Wareham, N. J., Wong, M.-Y., Hennings, S., Mitchell, J., Rennie, K., Cruickshank, K., & Day, N. E. (2000). Quantifying the association between habitual energy expenditure and blood pressure. International Journal of Epidemiology, 29(4), 655–660. https://doi.org/10.1093/ije/29.4.655
Witvrouw, E., Danneels, L., Asselman, P., D'Have, T., & Cambier, D. (2003). Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *The American Journal of Sports Medicine, 31*(1), 41–46. https://doi.org/10.1177/03635465030310011801