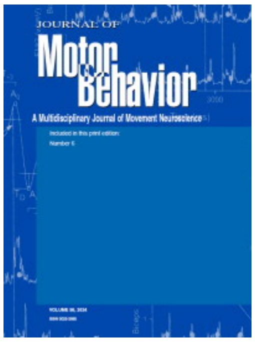

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Factors Influencing Gait Performance: Comfortable Linear Gait and Complex Gait in School-Aged Children in a Dual-Task Model

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ABSTRACT. The aim of this study was to determine the effect of cognitive interference by using the Dual-Task (DT) paradigm on gait parameters according to sex, and age. Additionally, we aim to explore the relationship between Dual-Task-Cost (DTC), physical fitness, cognitive functioning, and weight status in schoolchildren. One hundred schoolchildren participated in this study (age = 8.83 ± 1.82 years). They were randomly assigned to Comfortable Linear Gait (CLG: gait in a straight path) or Complex Gait (CG: gait over obstacles) with and without interference. For CLG, boys and girls showed a reduction in gait speed ($p < 0.001$), cadence ($p < 0.01$), and step length ($p < 0.001$). In addition, double support time ($p < 0.05$) and cadence coefficient of variance (boys= $p < 0.01$; girls= $p < 0.05$) increased in the DT condition. In the CG, both sexes ($p < 0.001$) exhibited a worse execution time. There were significant effects on speed DTC between 8-9 vs. 10-11 years in CLG and 6-7 vs. 10–11 years in CGT ($p < 0.05$). In conclusion, gait parameters during CLG and CG are modified in the DT condition, resulting in a slower gait with shorter steps, regardless of age and sex. DTC is associated with physical fitness and cognitive function.

Keywords: complex gait, dual task, comfortable linear gait, schoolchildren, dual-task cost

Introduction

Early motor and cognitive development is crucial for overall well-being and progress from early childhood onwards (Shi & Feng, 2022). In this golden period, the child's brain is very receptive to learning and development, making it a critical period for the acquisition of basic motor skills due to the maximum brain plasticity of the stage (Veldman et al., 2019). In this sense, these skills acquired at this stage not only enable physical independence but are also integral to cognitive and social development (Lyu, 2023). Since basic motor skills are essential for mastering complex motor skills, it's crucial to recognise that developing these skills in childhood helps identify deficits and supports overall development later in life (Karadeniz et al., 2023). Moreover, fostering the development of basic motor skills is key to creating effective interventions and enriching learning environments (Latorre-Román et al., 2021).

In this context, Dual-Task (DT) activities are particularly relevant for the assessment of cognitive-motor tasks. DT involves performing two tasks simultaneously, typically one motor and one cognitive, and is representative of many daily situations where children must manage multiple demands at the same time (Saxena et al., 2019). In this context, there is scientific interest in the relationship between motor and cognitive tasks, as the neocerebellum and the dorsolateral prefrontal cortex are activated simultaneously during the execution of a motor–cognitive task, showing overlap and interrelation during the execution of a DT (Veldman et al., 2019). In this sense, Piaget and Cook (1952) theory of cognitive development highlights the integral role of bodily movement in shaping cognitive processes. This approach emphasises the holistic integration of mind and body, suggesting that our environment and actions deeply influence cognitive growth. Therefore, the ability to perform DT effectively is an important indicator of motor and cognitive development, as it requires complex integration and coordination of diverse skills (Klotzbier et al., 2020)

The investigation of dual-task performance in gait focuses specifically on the cognitive functions of intelligence and attention due to their significant impact on walking tasks under cognitive load (Plummer et al., 2011). Intelligence is explored in terms of cognitive flexibility and problem-solving, which are essential for processing complex instructions during locomotion (Wollesen et al., 2019). Attention is assessed through its selective and sustained components, critical for managing gait stability and navigation amid distractions (Klotzbier et al., 2020). Employing a DT methodology simulates real-world scenarios, such as navigating busy environments while engaging in cognitive tasks, to study how children balance these demands (Saxena et al., 2017).

Daily activities often require children to perform cognitive and motor tasks simultaneously, such as walking to school while talking to a classmate or carrying a school bag (Beurskens et al., 2015). Within the school context, students frequently engage in DT activities, like listening and writing or participating in physical

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education sessions requiring motor actions with cognitive interference. These scenarios highlight the importance of DT, as they demand coordination and test the ability to perform tasks successfully during everyday activities (Möhring et al., 2021). Plummer and Eskes (2015) argued that performing two tasks synchronously often reduces performance due to limited attention. This loss of performance is called dual-task cost (DTC), which can be calculated with the following equation: [(dual task—single task)/single task] × 100 (Plummer & Eskes, 2015). A lower DTC represents better motor–cognitive performance and vice versa (Bianchini et al., 2022). Therefore, the DT paradigm is an ecologically valid approach to assessing cognitive function relative to motor demands (Klotzbier et al., 2020).

As explained earlier, basic motor skills include fine and gross motor coordination necessary for activities of daily life (Sigmundsson et al., 2021). Fine motor skills use small muscle groups for tasks like hand and finger movements and eye-hand coordination, whereas gross motor skills involve large muscle groups, such as the torso and legs, for activities like walking and throwing (Vandoni et al., 2024). In this regard, gait is often assumed to be an automated skill, involving minimal use of executive functions and attentional resources (Ranchet et al., 2020).

As regards Comfortable Linear Gait (CLG), is a natural, efficient walking pace used to develop therapeutic strategies and assess gait in individuals with impairments (Linder et al., 2023). In this regard, in daily life, the environmental conditions act as influencing factors on the kinematic parameters of gait, as daily demands force human beings to move not only in a straight line, but also to be prepared to avoid obstacles and to attend to other external stimuli (people, objects, or animals) that appear frequently during daily displacement (Schott, 2015). In that sense, Párraga-Montilla et al. (2021) concluded that Complex Gait (CG) (i.e., walking while attending to external motor or cognitive stimuli such as avoiding obstacles) involves greater participation of the cortical function (prefrontal cortex). Indeed, executive functions such as planning, attention, and working memory contribute to developing a more stable gait (Davis et al., 2011). Therefore, executive functions have influenced CLG and CG, as they are involved in the coordination of movements and the ability to walk with obstacles (Yogev-Seligmann et al., 2008).

In addition, given that physical fitness and weight status may be associated with executive functioning, these parameters could also have an influence on gait parameters (Kung et al., 2019; Molina-Garcia et al., 2020; Montes-Alguacil et al., 2019). In this line, children who participated in physical activities showed greater brain plasticity, thus improving their cognitive function and academic performance (Chaddock-Heyman et al., 2014). Thus, improved physical fitness can be linked to improved cognitive processes, such as attention, memory, and executive function (Chaddock et al., 2011; Latorre-Román et al., 2020). In addition, maintaining a healthy weight status is often associated with more optimal brain function because it reduces inflammation, improves cardiovascular health, and enhances insulin sensitivity, all of which support better neural processes and cognitive function. (Kamijo et al., 2014). This connection is especially significant in children, as early habits can have an impact on physical-cognitive development (Davis et al., 2011).

As children move from childhood to adolescence, their multitasking skills improve significantly. This improvement is attributed to several developmental factors, such as an increase in working memory and processing speed, as well as a progression from concrete to formal operational stages in cognitive development (Spencer, 2020). These stages enable them to perform complex tasks more efficiently (Fischer & Bullock, 1984). In addition, motor development contributes to their ability to perform not only cognitive, but also complex physical tasks, as evidenced by studies showing a reduction in gait variability, reflecting improvements in gait automaticity and regularity (Hausdorff, 2005; Hausdorff et al., 1999). This maturation of motor coordination is closely related to the development of cognitive skills (Belmonti et al., 2013). DTC, which measures the decline in performance when a simple task competes with a more demanding task for attentional resources, decreases as children age (Hinton & Vallis, 2015). This decrease in DTC indicates critical developmental stages where children are less susceptible to task interference, suggesting an interconnected maturation of cognitive and motor skills (Abbruzzese et al., 2014).

Previous research has shown that DTC in gait parameters is reflected in decreased gait speed, cadence, and step length while increasing single and double support time, and gait variability in the DT condition, as cognitive load competes for attentional resources required for motor control (Chauvel et al., 2017; Plummer-D'Amato et al., 2010; Saxena et al., 2017; Strobach & Karbach, 2020; Wollesen et al., 2019). The authors demonstrated that although gait is executed in an automated way, it requires attentional and executive processes for its effective execution. Further studies have focused on the study of gait under a cognitive test (Rabaglietti et al., 2019), showing that verbal, arithmetic, and visual fluency tests (Strobach & Karbach, 2020) negatively affect the kinematic parameters of gait.

On the other hand, it is important to point out that during childhood and adolescence, sex differentiates gait parameters between boys and girls due to biomechanical and hormonal factors (Sudlow et al., 2023). Paschaleri et al. (2023) showed that girls have a more mature manifestation of gait parameters than boys due to the influence of the maturation period and sex characteristics. Similarly, Möhring et al. (2021) concluded that girls show a more comfortable gait and lower stride variability than boys in the DT condition. In contrast, Latorre-Román et al. (2022) reported that there are no relevant differences in gait parameters with respect to sex; however, the authors demonstrated that age influences gait maturation.

In terms of differences in the DT paradigm according to age groups, Hagmann-von et al. (2016) showed a significant age effect on gait performance under the DT paradigm. In contrast, Saxena et al. (2019) found no age-related differences in the DTC of the dual task. On the other hand, children with insufficient motor development show greater variability in gait under DT conditions compared to their peers (Bejerot et al., 2013). Therefore, this discrepancy highlights the nuanced role that sex and biological maturation play, alongside environmental influences, in shaping the development of gait patterns during childhood and adolescence.

To our knowledge, there is a gap in the scientific literature regarding the association between cognitive interference and gait within the DT paradigm in healthy children. Previous studies often lack standardised protocols for assessing the role of basic motor skills in verbal, arithmetic, or visual fluency during gait activities. Furthermore, there is limited evidence on the relationship between DT gait performance, physical fitness, weight status, and cognitive functioning in children.

Therefore, addressing this gap, the study aims to determine the effect of cognitive interference by using the DT paradigm on gait parameters according to sex, and age. Additionally, we aim to explore the relationship between DTC, physical fitness, cognitive functioning, and weight status in schoolchildren. We hypothesised that kinematic gait parameters and CG performance are affected during the DT condition, regardless of sex. However, these changes are less pronounced in older children, suggesting an age-related improvement. Furthermore, we propose that DTC is closely associated with specific aspects of cognitive functioning, physical fitness, and weight status.

Materials and Methods

Design and Participants

A cross-sectional study was conducted in a primary school (omitted to avoid identifying the authors). A total of 100 schoolchildren participated in this study (age = 8.83 ± 1.82 years). The participants were divided into three groups based on the primary education stages in Spain: first stage (group 1: $n = 28$, children aged 6–7 years), second stage (group 2: $n = 32$, children aged 8–9 years), and third stage (group 3: $n = 40$, children aged 10–11 years). A priori sample size was calculated using G*Power software (Erdfelder et al., 2009). The following parameters were selected: a medium effect size (Cohen's $d = 0.50$), and α level of 0.05, a power level of 0.80, three groups, and two measurements. Based on these criteria, the minimum required sample size was determined to be 84 participants (28 per group). This study included a total of 100 participants, ensuring an adequate sample size for detecting statistically significant differences between groups. The inclusion criteria were: (a) registered as a student in the school; (b) no physical and/or intellectual disabilities that affected gait performance; and (c) no disability and sensory or language impairment (this information was obtained through a questionnaire specifically designed for parents, in addition to reports from tutors and the physical education teacher). Moreover, the parents signed an informed consent form to allow their children to take part in this research. The study was approved by the Ethics Committee of the University of Jaén (Reference code: JUN.21/7.TES) and followed the ethical recommendations approved by the Declaration of Helsinki (Helsinki, 2013).

Materials and Procedures

Cognitive Testing

The child's aptitude to learn was assessed through the School Aptitude Test Level 1 (TEA-1). This test is designed for children between the ages of 8 and 12 years. The Spanish version of this test was used (Thurstone & Thurstone, 2005). This test assesses intelligence from three domains: verbal, numerical, and reasoning. It is structured in five different sections (drawings = 15; different words = 15; vocabulary = 20; reasoning = 27; calculation = 55). The total score is transformed into a direct score according to age, after that, the direct score is converted into Intelligence Quotient score (IQ score) (min = 15 to max = 147) according to the test manual, whereas the total score is calculated by adding both parts with minimum (0 points) and maximum (132 points) values. The test was not applied to the 6–7-year age group due to considerations of cognitive development and responsiveness appropriate to this age range (pedagogical indications and its complexity). In the current study, the TEA-1 demonstrated good reliability, with a Cronbach's α of 0.841. Similarly, Fernández et al. (2019) also observed strong reliability, reporting a Cronbach's α of 0.920, further supporting the reliability of this test.

The Perception of Similarities and Differences Test (Caras-R test) assesses selective attention, sustained attention, and the ability to perceive differences quickly on partially ordered stimulus patterns. The Spanish version of this test was used (Thurstone & Yela, 2009). It is composed of 60 graphic items (stimulus-blocks) grouped into three schematic drawings of faces (eyes, eyebrows, hair, and mouth), of which two faces are the same and one face is different. The test consists of crossing out the face that is different from the other two in the same block of faces. Test–retest reliability showed Cronbach's α of 0.89 (Carrillo-López, 2022). It should be noted that both test (i.e., TEA-1 and Caras-R test), as was pointed out in the introduction to this paper, are essential tools in our study to assess executive functions, such as planning, decision-making, and attention regulation, which are crucial for walking under DT conditions.

Cognitive Interference

Two tests—a VF task and the digit span test (DST) were used to provoke cognitive interference for CLG and CG, respectively.

The VF task assesses the linguistic ability to produce words according to cognitive ability in the shortest time possible (Montero-Odasso et al., 2009). This study, it comprised 31 questions of different categories and levels of difficulty (e.g., provide four girls' names, professions, insects, and colours). The questions were recorded in the mp3 format by qualified personnel in a professional recording studio. With respect to the question–answer times, the investigator was given 3 s to ask each question, and the participant was given 7 s to answer each question, although they were asked to answer each question as quickly as possible, as the questions were continuous. The VF task methodology is based on previous research (Andrade-Lara et al., 2024; Chatterjee et al., 2021).

The DST involved listening to an audio track with a sequence of numbers. The sequence starts with a two-digit series, and the number of digits increases progressively in each series (e.g., 9–7, 5-8-2, etc.). The test has eight levels (1–8), and each level has two series of numbers that the participants repeat while executing the gait test. The total audio time was 3 min and 40 s in the mp3 format. The answer time for each series was defined according to the time taken for each statement in each series (e.g., if the first series statement took 3 s, then the response time would be 3 s). The DST was structured according to the Wechsler Intelligence Scale for Children (fourth edition, WAIS-IV) (Wechsler, 2005). The DST has the cognitive ability (sequential memory, attention, and concentration) to recall a series in the given order (forward or backward). Scientific evidence (Bernal et al., 2003; Heinzel et al., 2013) has shown that arithmetic mental processes are associated with high levels of interference during DT walking.

Considering that VF measures cognitive flexibility, crucial in dual-demand tasks, while DST assesses working memory and attention, essential for managing multiple simultaneous tasks. This explicit connection to executive functions helps to understand their influence on children's ability to coordinate walking and other activities under DT conditions.

Physical Fitness

Three tests were used to measure physical fitness.

A standing long jump was used to assess lower limb strength (Latorre-Román et al., 2018). Two attempts were allowed, and the best attempt was recorded. A longer jump distance (measured from the take-off point and the heel of the nearest foot at landing) implies better performance.

The Léger test was used to measure cardiorespiratory fitness (Léger et al., 1988). It consists of an incremental running test in which the participant is required to run back and forth and back again between two lines (the distance between lines is 20 m). The test starts with an initial speed of 8.5 km/h and increases by 0.5 km/h per minute (period). The pace for each period is indicated with audible signals. The test finishes when the participant is not able to reach the end lines concurrently with the audio signals at two consecutive times

Finally, a 25-m sprint test was performed on a flat, hard, non-slip surface. Two photocells (WITTY, Microgate Srl; Bolzano, Italy; 0.001-s accuracy) were used to register the time (s), with one situated at the beginning and one at the end of the 25-m corridor. Two attempts were performed, and the best attempt was recorded.

Anthropometric Measures

Body mass (kg) was measured using a weighing scale (Seca 899, Hamburg, Germany) and body height (cm) was assessed with a stadiometer (Seca 222). Body mass index was calculated by dividing body mass (kg) by body height (in metres) squared.

Gait Assessment

The Optogait system (Microgait Srl) was used to assess the kinematic parameters of CLG. This system employs photocells to automatically record gait parameters while a person is walking. Each participant walked along 5-m Optogait corridor 10 times. To ensure that the displacement was consistent over 5 m, the participants were instructed to turn around at a cone located 2.5 m from the start and end point of the Optogait corridor. The test was conducted in two different conditions: in the ST condition, the participants had to walk through the corridor with a comfortable gait without interference, while in the DT condition, the participants had to walk using a comfortable gait while responding to the questions of the VF task (Figure 1).

The kinematic gait parameters analysed were speed (s), cadence (step/s), step length (cm), single and double support (s), and the walk ratio (WR). The WR represents the relationship between the step length and the frequency of leg movements. It is calculated as the mean step length divided by the cadence. Moreover, variability in step length and cadence was analysed in terms of the

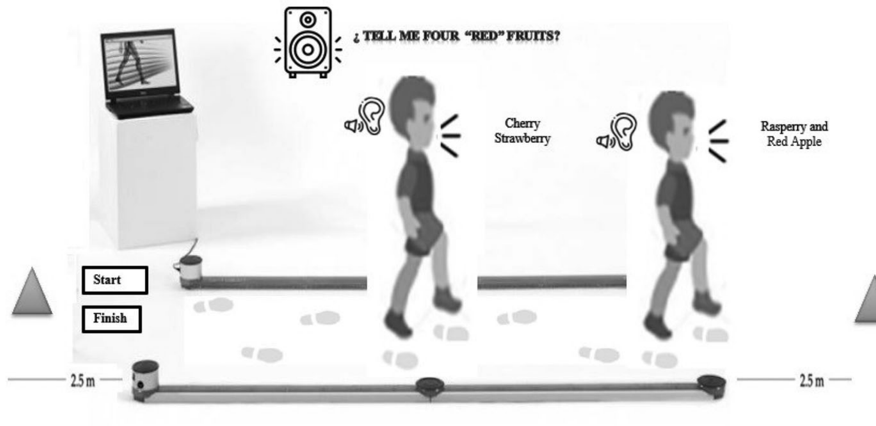

FIGURE 1. Comfortable linear gait beneath verbal fluency interference.

coefficient of variation (CV) among the participants, given as [percentage standard deviation (SD)/ mean] × 100.

The gait parameters speed, cadence, and step length were normalised following the equation by Stansfield et al. (2006) and Hof (1996):

$$\text{Normalised speed} = \text{speed} \times \frac{1}{\sqrt{\left(\text{Height} \times 9.81\frac{m2}{s}(\text{gravity value}).\right.}}$$

$$\text{Normalised cadence} = \text{cadence} \times \sqrt{\frac{\text{Height}}{9.81\frac{m2}{s}}}$$

$$\text{Normalised step length} = \text{step length}\frac{1}{\text{Height}}$$

Complex Gait

The complex gait test (CGT) was used to assess CG. This test consists of walking as fast as possible while overcoming a series of obstacles (Figure 2). The test was performed in a controlled outdoor environment where obstacles simulated the characteristics of social walking. Participants performed two conditions: CGT without interference (ST) where they had to walk as fast as possible to complete the three laps, while in the DT condition, the participants had to repeat different numerical series (DST) while completing three laps as fast as possible. The execution time was recorded in seconds (Figure 2). The time (s) to complete three consecutive laps of CGT as fast as possible (without starting to run) in each condition was recorded. Each participant performed one trial during the audio explanation of the DT condition in CLG and CGT to verify that they understood the dynamics of the test.

Procedure

The evaluation protocol was carried out over four different sessions in the school. In addition, each session lasted 60 min. During the first session, the participants completed the TEA-1. The gait assessment was carried out during the second and third sessions. In addition, anthropometric measurements were recorded during the second session. A convenience sampling method was used in this study. Moreover, participants were randomly assigned to different tests (CLG and CGT) to prevent interference and avoid any learning effects. Consequently, the tests were structured as follows: (1) CLG without interference, (2) CLG with interference (VF task), (3) CGT without interference, and (4) CGT with interference (the DST). Each participant performed each test with and without interference (audio condition). They also performed one trial with the CLG and CGT to ensure they understood the test. Regarding the DT condition, the children performed one short trial (different from the audio that was used in the study to avoid a learning effect) during the audio explanation of the test development to check that they understood the dynamics of the DT condition. The correct and incorrect answers were not recorded during this trial, but the participant was told whether their answer was 'correct' or 'incorrect'. Finally, the Caras-R and physical fitness tests were conducted during the fourth session. Additionally, all 100 schoolchildren completed the study, with no dropouts or expressed desire to leave during the evaluation.

Statistical Analysis

The data were analysed with SPSS v.19.0 for Windows (SPSS Inc, Chicago, IL, USA). The data are

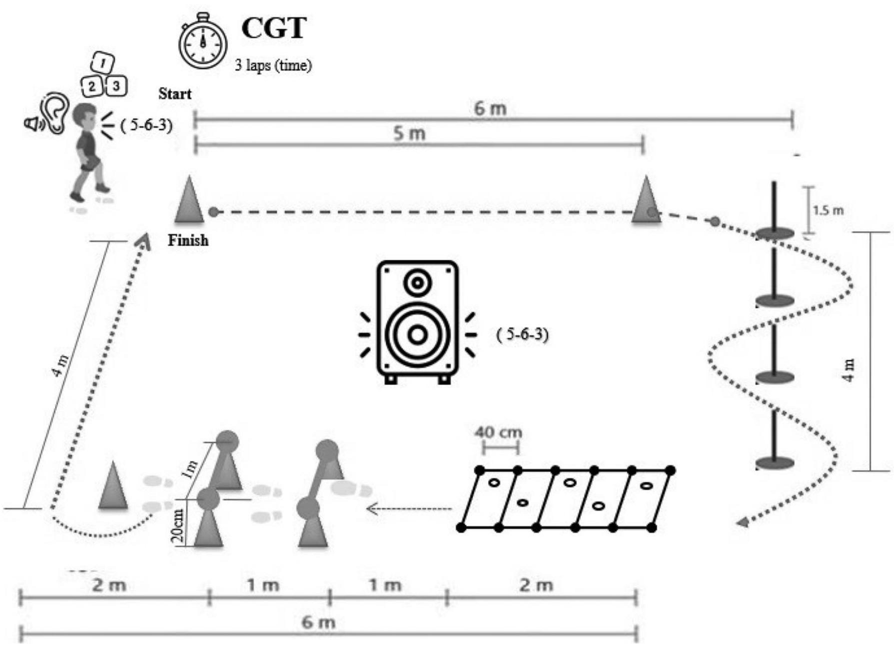

FIGURE 2. Complex gait test beneath interference condition (Digit Spam Test).

presented as means, standard deviations, and percentages. Prior to analysis, the Kolmogorov–Smirnov test and Levene's test were used to determine whether the data followed a normal distribution and showed homoscedasticity, respectively. Furthermore, the sample size was determined using the G*Power software (version 3.1.9.6).

A two-way ANOVA was conducted with 2 Sex (Boys vs. Girls) x 3 Age groups (6-7 years vs. 8–9 years vs. 10–11 years) x 2 Condition (ST vs. DT) as factors, followed by Bonferroni-adjusted post-hoc tests. This analysis was used to determine differences between the ST and DT conditions based on sex and age groups. The effect sizes for the differences between the groups are expressed as Cohen's d, which was interpreted as: trivial (<0.2), small (0.2–0.49), moderate (0.5–0.79), and large (≥0.8) (Cohen, 1988). UNIVARIATE analysis adjusted by the Bonferroni test was used to determine DTC differences between the sexes and the age groups. Consequently, partial correlations (adjusted by age and sex) were used to determine the association between DTC, fitness, anthropometric and cognitive variables. In addition, the results of the overall DTC averages are expressed as percentages. The significance level was set at $p \leq 0.05$.

Results

Table 1 displays age, anthropometric data, physical fitness, and cognitive functioning measures divided by sex and age group. The Léger test results showed that boys exhibited greater aerobic capacity compared to girls ($p < 0.05$). In the standing long jump and 25-m sprint, boys performed better than girls ($p < 0.05$). With regard to the age groups in the Léger test ($p < 0.01$), children aged 10–11 years old performed better in the standing long jump ($p < 0.001$) and 25-m sprint ($p < 0.05$) than the rest of the children. In terms of cognitive abilities, 8–9-year-old children scored higher on the TEA-1 IQ test than those aged 10–11 years ($p < 0.05$).

The kinematic gait parameters according to each sex and age gropp for the CLG and CGT tests are presented in Table 2. The results in the CLG showed significant decreases in gait speed ($p < 0.001$), cadence ($p < 0.01$), and step length ($p < 0.001$) under the DT condition for both sexes. Double support time increased ($p < 0.05$) and cadence variability heightened for boys ($p < 0.01$) and girls ($p < 0.05$) under DT. Boys also showed an increase in single support time under DT ($p < 0.05$). Regarding CGT, boys and girls exhibited a worse performance time in the DT condition compared with the ST condition ($p < 0.001$). These results demonstrate that DT condition negatively affected gait parameters, regardless of age group (p range from < 0.001 to 0.05) or sex ($p > 0.05$).

Regarding the percentage of DTC of the participants, figure 3 shows the DTC results by sex. There were no significant sex differences in DTC ($p > 0.05$).

TABLE 1. Age, anthropometric, physical fitness and cognitive functioning measures by sex and ages. Data are shown as mean and standard deviation (SD).

Variables	*n*	Total mean (SD)	Boys mean (SD) *n* = 56	Girls mean (SD) *n* = 44	*p*-value	Cohen's d	*n*	6–7 years mean (SD) a	*n*	8-9 years mean (SD) b	*n*	10-11 years mean (SD) c	p-value	Post-hoc
Age (years)	100	8.83 (1.82)	8.93 (1.89)	8.70 (1.73)	0.544	0.126	28	6.46 (0.50)	32	8.59 (0.49)	40	10.67 (0.69)	<0.001	a < b***;a < c***; b < c***
Weight (kg)	100	36.14 (10.66)	36.73 (9.16)	35.39 (12.39)	0.534	0.123	28	29.10 (7.83)	32	34.49 (9.34)	40	42.39 (9.95)	<0.001	a < c***; b < c**
Height (m)	100	1.38 (0.12)	1.39 (0.11)	1.36 (0.13)	0.155	0.285	28	1.26 (0.08)	32	1.34 (0.07)	40	1.49 (0.07)	<0.001	a < b***; a < c** b < c***
BMI (kg/m^2)	100	18.60 (3.71)	18.61 (3.46)	18.59 (4.04)	0.984	0.004	28	18.04 (3.29)	32	18.78 (4.28)	40	18.84 (3.55)	0.650	
25m Sprint (s)	100	5.81 (0.67)	5.68 (0.68)	5.97 (0.62)	0.029	0.450	28	5.95 (0.71)	32	5.98 (0.59)	40	5.57 (0.64)	0.014	b > c*
Leger test (bouts)	100	2.08 (1.17)	2.33 (1.34)	1.76 (0.82)	0.010	0.517	28	1.60 (0.64)	32	1.87 (1.06)	40	2.58 (1.36)	0.001	a < c**; b < c*
Standing long jump (m)	100	1.24 (0.28)	1.32 (0.29)	1.14 (0.24)	0.001	0.276	28	1.03 (0.17)	32	1.26 (0.25)	40	1.38 (0.28)	<0.001	a < b**; a < c***
CARAS-R Test (±100)	100	77.30 (22.93)	73.91 (25.84)	81.63 (17.96)	0.082	0.346	28	75.65 (23.60)	32	74.64 (27.01)	40	80.59 (18.72)	0.502	
TEA-1 score (0–132)	62	41.30 (17.77)	39.37 (18.66)	44.16 (16.32)	0.290	0.273	n/a	n/a	23	43.21 (16.11)	39	40.17 (18.80)	0.520	
IQ score TEA (15–117)	56	77.05 (16.60)	76.65 (14.07)	77.58 (19.79)	0.846	0.054	n/a	n/a	23	83.21 (15.87)	33	72.75 (15.94)	0.019	

BMI: body mass index; n/a: not applicable; IQ: intelligence quotient; TEA: school aptitude test level 1 (TEA-1).
*$p < 0.05$,
**$p < 0.01$,
***$p < 0.001$. Two-way analysis of variance (ANOVA) adjusted by the Bonferroni test was used.

TABLE 2. Kinematic parameters of gait by sex and age groups under ST and DT conditions.

		Boys						Girls					
Variable	Condition	Total $n = 56$	6–7 years $n = 15$ a	8–9 years $n = 17$ b	10–11 years $n = 24$ c	p-value	Post-hoc	Total $n = 44$	6–7 years $n = 13$ a	8–9 years $n = 15$ b	10–11 years $n = 16$ c	p-value	Post-hoc
Comfortable Linear Gait													
Speed (m/s)	ST	1.22 (0.15)	1.21 (0.21)	1.19 (0.13)	1.25 (0.12)	0.529		1.19 (0.21)	1.11 (0.19)	1.21 (0.23)	1.25 (0.18)	0.191	
	DT	1.07 (0.18)	1.05 (0.20)	1.03 (0.20)	1.12 (0.14)	0.286		1.04 (0.16)	0.95 (0.16)	1.05 (0.17)	1.11 (0.11)	0.033	a < c*
	p-value	<0.001	<0.001	<0.001	<0.001			<0.001	0.001	<0.001	0.001		
	Cohen's d	0.905	0.780	0.949	0.997			0.804	0.911	0.791	0.939		
Speed normalised	ST	0.33 (0.04)	0.34 (0.06)	0.32 (0.03)	0.32 (0.03)	0.621		0.32 (0.05)	0.32 (0.05)	0.33 (0.05)	0.32 (0.06)	0.780	
	DT	0.29 (0.05)	0.29 (0.06)	0.28 (0.05)	0.29 (0.03)	0.719		0.28 (0.04)	0.27 (0.04)	0.29 (0.04)	0.29 (0.03)	0.690	
	p-value	<0.001	<0.001	<0.001	0.001			<0.001	0.001	<0.001	0.002		
	Cohen's d	0.883	0.833	0.970	1			0.883	1.104	0.883	0.632		
Cadence (step/s)	ST	2.12 (0.20)	2.26 (0.30)	2.10 (0.12)	2.05 (0.13)	0.010		2.10 (0.22)	2.18 (0.16)	2.14 (0.25)	2.00 (0.19)	0.048	
	DT	2.02 (0.25)	2.13 (0.27)	1.96 (0.22)	2.00 (0.26)	0.138		1.98 (0.23)	2.06 (0.22)	1.99 (0.21)	1.90 (0.26)	0.208	
	p-value	0.001	0.036	0.018	0.273			0.001	0.087	0.015	0.089		
	Cohen's d	0.441	0.805	0.790	0.966			0.533	0.624	0.650	0.439		
Cadence Normalised	ST	0.80 (0.06)	0.82 (0.10)	0.78 (0.04)	0.80 (0.05)	0.328		0.78 (0.07)	0.76 (0.06)	0.79 (0.08)	0.78 (0.08)	0.694	
	DT	0.76 (0.09)	0.77 (0.09)	0.72 (0.07)	0.78 (0.10)	0.177		0.73 (0.08)	0.72 (0.08)	0.73 (0.07)	0.74 (0.10)	0.918	
	p-value	0.002	0.046	0.019	0.263			0.001	0.111	0.019	0.080		
	Cohen's d	0.522	0.525	1.052	0.252			0.880	0.565	0.798	0.441		
Step length (cm)	ST	60.55 (5.88)	56.24 (5.79)	59.64 (5.71)	63.89 (3.89)	0.001	a < c**	59.16 (8.16)	53.30 (6.56)	58.65 (6.06)	64.41 (7.93)	<0.001	a < c*** b < c*
	DT	55.57 (6.65)	51.43 (5.97)	54.09 (6.08)	59.21 (5.64)	<0.001	a < c*** b < c*	54.40 (7.09)	48.20 (4.61)	53.94 (6.16)	59.88 (5.11)	<0.001	a < b* a < c***
	p-value	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	<0.001		
	Cohen's d	0.793	0.817	0.941	0.111	0.728		0.623	0.900	0.771	0.679	0.927	
Step length normalised	ST	43.44 (4.39)	43.64 (5.32)	44.10 (4.97)	42.85 (3.33)			43.59 (5.63)	43.62 (5.24)	43.94 (5.52)	43.23 (6.34)		
	DT	39.84 (4.58)	39.82 (4.61)	40.02 (5.21)	39.72 (4.27)	0.979		40.04 4.55	39.50 (4.29)	40.37 (5.07)	40.18 (4.50)	0.877	
	p-value	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001	<0.001	0.001		
	Cohen's d	0.802	0.767	0.801	0.809			1.045	0.860	0.673	0.554		
WR (cm/step x min)	ST	0.48 (0.06)	0.42 (0.06)	0.47 (0.05)	0.52 (0.04)	<0.001	a < b* a < c***	0.48 (0.08)	0.41 (0.47)	0.46 (0.05)	0.55 (0.08)	<0.001	a < c*** b < c**
	DT	0.46 (0.06)	0.41 (0.05)	0.46 (0.04)	0.50 (0.06)	0.004	a < c*	0.47 (0.12)	0.39 (0.05)	0.45 (0.06)	0.54 (0.15)	<0.001	a < c*** b < c*
	p-value	0.109	0.450	0.469	0.160			0.606	0.427	0.829	0.867		
	Cohen's d	0.336	0.187	0.227	0.400			0.099	0.062	0.187	0.085		
Single support (s)	ST	0.40 (0.08)	0.37 (0.05)	0.39 (0.08)	0.43 (0.09)	0.065		0.40 (0.06)	0.38 (0.04)	0.39 (0.04)	0.44 (0.08)	0.106	
	DT	0.43 (0.08)	0.38 (0.05)	0.45 (0.08)	0.44 (0.09)	0.024	a < b* a < c*	0.41 (0.06)	0.39 (0.04)	0.42 (0.08)	0.42 (0.04)	0.544	
	p-value	0.019	0.610	0.005	0.486			0.517	0.672	0.175	0.484		
	Cohen's d	0.375	0.200	7.500	0.352			0.167	0.250	0.474	0.353		
Double support (s)	ST	0.16 (0.07)	0.16 (0.06)	0.16 (0.06)	0.16 (0.08)	0.959		0.16 (0.08)	0.16 (0.04)	0.18 (0.08)	0.13 (0.09)	0.136	
	DT	0.19 (0.09)	0.19 (0.06)	0.19 (0.11)	0.19 (0.09)	0.996		0.20 (0.08)	0.20 (0.08)	0.19 (0.09)	0.19 (0.07)	0.965	
	p-value	0.024	0.196	0.290	0.098			0.019	0.170	0.731	0.017		
	Cohen's d	0.372	0.339	0.339	0.666			0.500	0.632	0.117	0.744		
CV cadence (%)	ST	4.45 (1.57)	5.47 (1.84)	4.53 (1.45)	3.77 (1.10)	0.063		5.22 (3.07)	7.21 (4.62)	4.42 (1.42)	4.34 (1.76)	0.001	a > b** a > c**
	DT	6.25 (4.15)	6.51 (4.88)	6.72 (3.69)	5.76 (4.08)	0.767		6.48 (4.94)	9.22 (8.04)	5.78 (1.91)	4.92 (2.29)	0.029	a > c*
	p-value	0.003	0.346	0.037	0.024			0.044	0.092	0.222	0.586		
	Cohen's d	0.573	0.282	0.781	0.005			0.306	0.307	0.808	0.284		
CV sl (%)	ST	17.02 (5.56)	16.17 (8.76)	17.24 (4.03)	17.39 (3.92)	0.302		17.12 (5.88)	16.46 (3.79)	16.41 (2.31)	18.31 (8.95)	0.903	
	DT	17.63 (7.39)	19.26 (12.65)	16.52 (4.53)	17.41 (4.02)	0.294		16.85 (5.25)	16.38 (6.17)	15.27 (3.75)	18.70 (5.40)	0.043	a < c* b < c*
	p-value	0.916	0.865	0.687	0.775			0.718	0.600	0.496	0.679		
	Cohen's d	0.093	0.284	0.168	0.005			0.048	0.016	0.366	0.053		

(*CONTINUED*)

TABLE 2. (*Continued*).

Variable	Condition	Boys: Total $n=56$	Boys: 6–7 years $n=15$ a	Boys: 8–9 years $n=17$ b	Boys: 10–11 years $n=24$ c	p-value	Post-hoc	Girls: Total $n=44$	Girls: 6–7 years $n=13$ a	Girls: 8–9 years $n=15$ b	Girls: 10–11 years $n=16$ c	p-value	Post-hoc
Complex Gait													
CGT (s)	ST	16.82 (2.09)	18.63 (2.38)	16.32 (1.58)	16.04 (1.51)	0.002	a > b** a > c***	17.19 (1.88)	17.65 (2.18)	17.33 (2.05)	16.69 (1.40)	0.377	
	DT	20.89 (3.20)	23.86 (3.07)	20.50 (3.13)	19.31 (1.87)	<0.001	a > b** a > c***	20.28 (2.73)	21.37 (2.96)	21.19 (2.40)	18.53 (1.99)	0.004	a > c* b > c*
	p-value	<0.001	0.001	<0.001	<0.001			<0.001	0.001	0.001	<0.001		
	Cohen's d	1.505	1.904	1.686	1.924			1.318	1.431	1.729	1.069		

*$p < 0.5$.
**$p < 0.01$.
***$p < 0.001$ Denotes differences between age's groups in each condition and sex; ST: single task; DT: dual task; WR: walk ratio; CV: coefficient of variation.

Figure 4 presents DTC for the age groups for CLG and CGT. For CLG, there was a significant difference between the 8–9- and 10–11-year age groups in DTC speed ($M = 14.96 \pm 10.68$ vs 7.63 ± 6.03; F(2.94) = 3.575, $p = 0.038$) (Figure 4a). For the CGT, there was a significant difference in DTC speed between the 6–7- and 10–11-year age groups (25.60 ± 11.83 vs 18.32 ± 10.44; F(2.94) = 3.876, $p = 0.026$) (Figure 4b). There were no significant differences for the remaining variables between the groups.

In addition, Table 3 presents the partial correlations (adjusted by sex and age) between measures of physical and cognitive performance with DTC's gait variables.

Discussion

The aim of this study was to determine the effect of cognitive interference by using the DT paradigm on gait parameters according to sex, and age. Additionally, we aim to explore the relationship between DTC, physical fitness, cognitive functioning, and weight status in schoolchildren.

The results obtained in the current study confirm our main hypothesis, as the kinematic gait parameters were modified in boys and girls during the DT condition with respect to the ST condition; furthermore, DTC was negatively associated with fitness performance and cognitive test scores. These findings support the idea that CLG is affected when children have to manage cognitive interference, regardless of their sex. Gait velocity, step length, cadence, and step time decreased; however, CV cadence increased in boys and girls during the DT condition.

These results are consistent with previous research that demonstrated gait is adversely affected by the DT paradigm, leading to a decrease in the kinematic gait parameters and changes in gait variability (Horata & Kundakci, 2022; Hung et al., 2013; Manicolo et al., 2017; Schaefer et al., 2015). In particular, this finding is in agreement with Beurskens et al. (2015), who showed that boys and girls significantly decreased gait speed, stride length, and cadence, but increased gait variability during the DT condition compared with the ST condition. Likewise, comparing our results with Huang et al. (2003) we found that both studies show that performing a cognitive task while walking reduces speed, stride length, and cadence. On the other hand, Hung et al. (2013) focused on overweight and obese children, observing a greater impact in these groups. Our study covers a wider age range and considers additional variables, highlighting the importance of age- and fitness-specific analyses, noting that obese children may have greater difficulties in walking under dual-task conditions. In this regard, a recent systematic review (2021) concluded that DT affects overall walking performance by decreasing gait speed, step

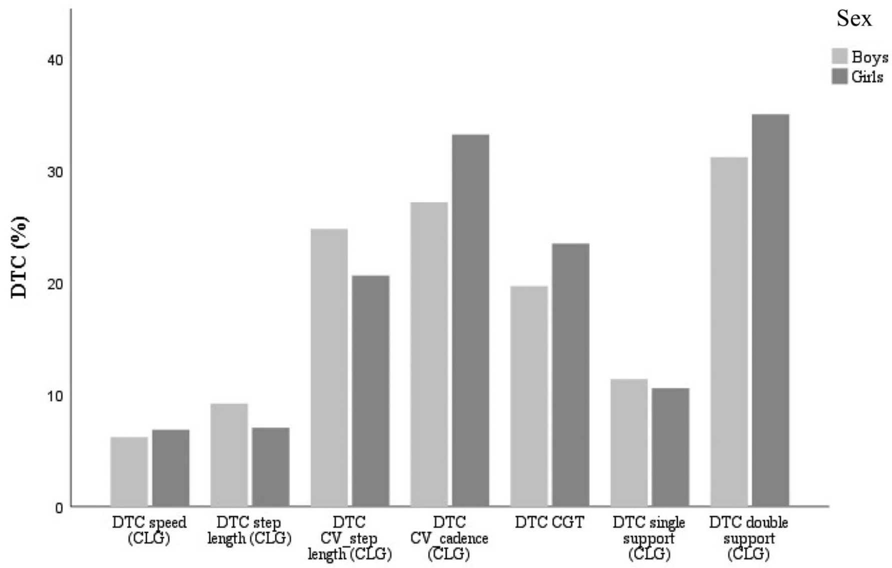

FIGURE 3. Results of dual task cost (DTC) on the gait variables analysed by sex.

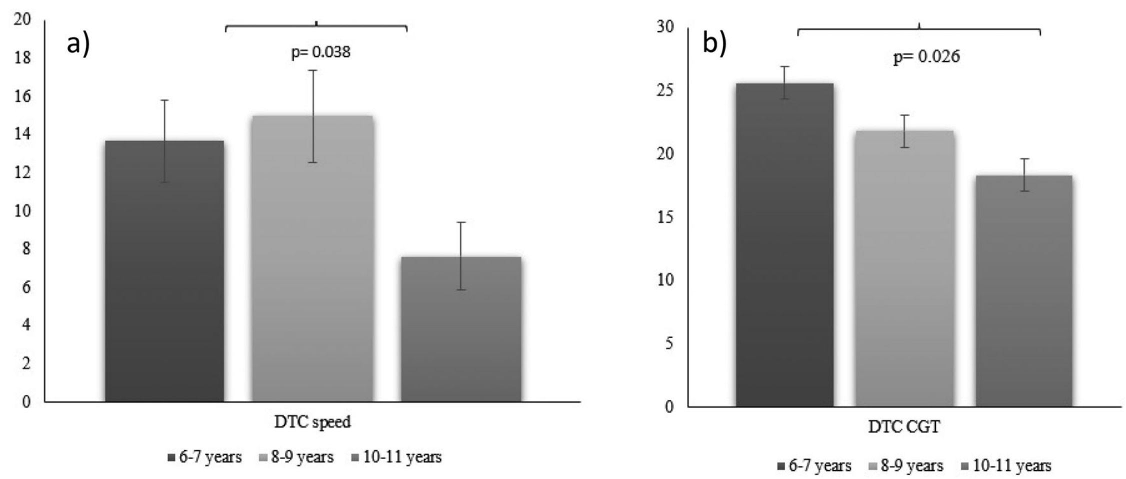

FIGURE 4. Dual task cost (DTC) in agés group on gait speed in Comfortable Gait linear (4a) and Complex Gait Test (4b).

length reduction, and cadence, while increasing the single and double support times, CV cadence, and CV SL in children. These results indicate that the competition for higher-level executive function resources is essential for walking. Therefore, younger children might not have satisfactory cognitive resources (Schott & Klotzbier, 2018).

A possible explanation for these results may be supported by the theory of limited attention span, which suggests that performing an additional task while walking divides cognitive resources, affecting speed, stride length and cadence (Al-Yahya et al., 2011). In this sense, previous research concluded that a higher magnitude of gait variation among children reflects impairments in executive functions and attentional resources (Yogev-Seligmann et al., 2008). Another possible explanation is the task prioritisation theory, which suggests that individuals prioritise the cognitive task over gait, resulting in a

TABLE 3. Results of partial correlations (adjusted by sex and age) between measures of physical and cognitive performance with DTC's gait variables.

	Variables	r	*p*-value
CLG	DTC speed vs. 25 m sprint	0.288	0.034
	DTC cadence vs. 25 m sprint	0.292	0.032
	DTC step length vs. 25 m sprint	0.274	0.044
	DTC step length vs. standing long jump	−0.280	0.040
	DTC step length vs. Léger test	−0.268	0.050
	DTC step length vs. TEA-1 scores	−0.313	0.021
CG	DTC CGT vs. TEA-1 scores	−0.301	0.027
	DTC CGT vs. TEA-1 IQ	−0.329	0.015

CLG: comfortable linear gait; CG: complex gait; DTC: dual task cost; IQ: intelligence quotient; TEA 1: school aptitude test level 1.

slower and less stable gait. This behaviour may be a strategy to maintain cognitive performance at the expense of gait efficiency (Yogev-Seligmann et al., 2012). However, in the current study, WR was not altered under the DT condition. As WR is a speed-independent index of the overall neuromotor gait control, as much as it reflects energy expenditure, balance, between-step variability, and attentional demand (Rota et al., 2011), measuring WR in the DT context could be a robust and sensitive indicator of gait maturity. Thus, the identification of such a parameter may contribute to better knowledge of the development of the control of gait (Hillman et al., 2009).

Another important finding in this study was that the time taken to perform the CGT increased with arithmetic interference with respect to the ST condition. It is possible that the DT condition involves using verbal processing and visuospatial working memory in the central nervous system to memorise the numbers and then subsequently enunciate sequential numbers (Cherng et al., 2007). During arithmetic interference, children are forced to divide their attentional resources, as they have to walk while solving the problem and respond to the cognitive task properly. Consequently, a reduction in gait speed is used as a strategy to prevent falls during CG (Hagmann-von et al., 2016). In addition, another main and novel feature of this test is that it consists of a speed task in the DT context. Anderson et al. (2011) highlighted that age might affect performance when a DT involves reaction time in that study, the objective was to solve the challenges as quickly as possible. It is important to note that the results of the present study cannot be compared with previous research because this is first study to assess the DT condition with the CGT.

In the current study, sex had no influence on walking performance under the DT condition. While limited research has explored sex differences in DT performance among children, the existing studies have presented inconsistencies. Some suggest no notable differences, while others, such as Möhring et al. (2021), have reported that girls show a more stable gait under the DT condition than boys. Further research needs to be conducted to establish whether sex influences DT performance in children.

Regarding age, the common conclusion in DT studies is that older children exhibit lower DTC than younger children (Irwin-Chase & Burns, 2000). A previous study showed that age influences DT performance for difficult or complex tasks; however, the results were inconclusive when the tasks were normalised to each individual's complexity level (Saxena et al., 2017). In the current study, there was no clear relationship between age and performance in the DT condition. A possible explanation for these results could be that the motor tasks and the cognitive interference were not adjusted to the level of each child. Furthermore, Saxena et al. (2019) concluded that the age group effects on DT performance could be driven by age differences in ST performance or differences in covariates such as physical fitness and cognitive functioning. A possible explanation for this discrepancy could be that the cognitive demands of the tasks used in the current study were not sufficiently challenging to reveal age-related differences. Furthermore, the number of participants was insufficient to detect subtle age-related effects. Hagmann-von et al. (2016) showed a significant age effect on gait performance under the DT paradigm; however, variables related to motor, cognitive performance, or psychosocial functioning were not predictive in the DT condition. Furthermore, in the present study, there were no differences between boys and girls in each age group. An explanation could be variations in experimental design, such as differences in task duration, environmental conditions or the way in which cognitive load was manipulated, which could explain the discrepancies between the two studies.

We found that younger children showed higher DTC speed than older children for CLG and CGT. Möhring et al. (2021) concluded that there is a progression in a child's ability to manage two simultaneous tasks as they get older. In contrast, other researchers (Irwin-Chase & Burns, 2000; Saxena et al., 2019) have concluded that the ability to coordinate two simultaneous tasks is the same in children aged 5, 6, 7, and 8 years when the tests are age appropriate and structured at comparable levels of difficulty. Thus, the aforementioned influence of age on DTC could be, at least partially, due to the components of the task and their age sensitivity. An explanation for these discrepant results among the studies may be the increase in prefrontal cortex myelination that occurs in middle childhood and early puberty (Möhring et al., 2021). In this context, an important consideration in the development of dual-task protocols is to ensure that the tasks are age-appropriate (Diamond, 2013). This involves adjusting the complexity of tasks to match the children's developmental stage. In addition, prior exposure to similar tasks may affect performance, so control measures are needed to account for this variability (Wollesen et al., 2019). To address these challenges, adaptive tests can be implemented to adjust difficulty in real time based on each child's performance (Schott et al., 2016)

Finally, DTC in CLG displayed a negative correlation with physical performance and the TEA-1 score; in other words, worse physical fitness and cognitive performance was associated with higher DTC. On the other hand, there was no association between DTC of the analysed gait variables and weight status. The present findings seem to be consistent with previous research that found a negative association between working memory skills (forward and backward numerical series) and DTC for walking ability (carrying a glass of water) (Rabaglietti et al., 2019). These findings may be related to the fact that to execute demanding concurrent tasks, children tend to use both visuospatial processing and the regulatory function of language (inner speech) to support their performance on more demanding executive tasks (Baddeley, 2012). Thus, a higher DTC in gait seems to be due to the involvement of cortical attentional processes while walking in the DT context (Auvinet et al., 2017). These results could have an implication for children's academic performance, as children who are not capable of maintaining concentration during DT activities in the school (i.e., writing and listening while the teacher is talking) may have lower academic performance (Schleepen & Jonkman, 2010).

Strength and Limitations

There are some limitations that should be mentioned: (1) the cross-sectional nature of our current study did not allow us to determine a cause–effect relationship between fitness, cognitive function, and DTC; (2) The limited number of the participants included in this study. Specifically, the small group size; (3) All the participants attended the same school, and living in the same city and environment could have had an influence on the participants. Therefore, the generalisability of our results may be limited. Nevertheless, a strength of this study is that it was conducted in an ecological environment: the assessment was carried out in a school setting. Moreover, to our knowledge, this is the first study carried out on schoolchildren under the cognitive–motor DT paradigm that analysed the influence of age, sex, and other predictive variables on CLG and CG performance. In addition, we have provided a standardised protocol that could be used in other studies.

Practical Application

From a practical point of view, better performance during the DT condition implies better motor and cognitive development (Wollesen et al., 2022). In this regard, there are no protocols providing standardised instruments and methodologies for the assessment of the DT condition. Therefore, extending these methodologies could contribute to predicting and identifying children with disorders as well as gifted children in the educational environment.

Conclusion

To sum up, kinematic gait parameters during CLG and CG are modified in the DT condition, resulting in a slower gait with shorter steps, regardless of age and sex. These results suggest that, although no significant relationship with sex was identified, the differences in DTC between age groups indicate that age plays an important role in the changes observed under DT condition. In addition, we found several correlations between DTC, physical fitness and cognitive functioning. These results suggest a progressive development in motor and cognitive control as the age of children increases.

Future studies should expand the number of participants assessed and explore the influence of external factors such as academic performance, lifestyle, and physical activity level to know how these factors can have an influence on DTC. Furthermore, it would be beneficial to investigate the influence of other executive functions in longitudinal designs in the dual environment in order to develop specific training protocols to improve DT performance in schools.

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