Exploring Associations Between Motor Competence, Executive Function, and Academic Attainment in Children in England.

Ayva-Mae Gilmour[1,2*], Mhairi J. MacDonald[1,2], Lauren Clifford[1,2], Stuart J. Fairclough[1,2], Jordan Banks[3], Peter Edwards[1], and Richard Tyler[1,2]

[1]Sport, Physical Activity, Health, and Wellbeing Research Group, Dept. Sport and Physical Activity, Edge Hill University, UK

[2]International Centre for Applied Research with Children, Young People, Pregnant Women and Families (iCARE), Edge Hill University, UK.

[3]Division of Health Research, Faculty of Health and Medicine, Lancaster University, Lancaster, LA1 4YW, UK.

Author Note

Ayva-Mae Gilmour https://orcid.org/0009-0000-5515-3256
Mhairi MacDonald https://orcid.org/0000-0001-6466-9617
Lauren Clifford https://orcid.org/0009-0005-5861-2127
Stuart J. Fairclough https://orcid.org/0000-0001-8358-1979
Jordan Banks https://orcid.org/0009-0007-2187-788X
Richard Tyler https://orcid.org/0000-0001-9756-5582

*Corresponding author: Ayva-Mae Gilmour; gilmoa@edgehill.ac.uk; Sport, Physical Activity, Health, and Wellbeing Research Group, Dept. Sport and Physical Activity, Edge Hill University, Ormskirk, Lancashire, L39 4QP, UK.

Abstract

Motor competence supports physical, emotional, and mental health, but its cognitive impact is understated. Motor-cognitive links remain underexplored, and motor competence's role in academic attainment, including the mediating influence of executive function, is limited. This research aimed to 1) investigate associations between motor competence and executive functions in 8-9-year-old children in England and 2) examine whether greater motor competence has a positive impact on executive function and academic attainment. Two hundred and forty seven children (51.4% girls; age 8.7 ± .4 years; 77.7% white British; 5 ± 3.1 deprivation decile; 73.3% healthy weight) across Pennine Lancashire completed a motor competence circuit, and executive function tests. Attainment across reading, writing, and mathematics assessed academic attainment. Direct effects were found between motor competence and executive function (β=-2.55, 95% CI [-4.87, -0.24]), motor competence and academic attainment (β=0.57, 95% CI [0.16, 0.98]), and executive function and academic attainment (β=-0.13, 95% CI [-0.24, -0.02]). Executive function mediated the indirect motor competence-academic attainment association (β=0.20, p=0.01). Multi-group analyses found a significant deprivation group effect (p=0.03). The motor-cognitive phenomenon is complex, requiring future research. The current findings show that motor and cognitive skills intertwine to support academic achievement. Therefore, using educational approaches that integrate these skills may improve attainment.

Keywords: Children, movement skills, cognition, educational performance, deprivation.

Exploring Associations Between Motor Competence, Executive Function, and Academic Attainment in Children in England.

Movement is essential for quality of life, contributing to physical, emotional, and mental health benefits such as improved strength, well-being, and reduced anxiety (Abdin et al., 2018; Adamson et al., 2015; Adsett et al., 2015; Bouchard et al., 2007). Motor competence refers to the development and performance of fundamental, combined and complex movement skills that are intended to achieve a goal in a precise and coordinated way, without error (Hulteen et al., 2018; Tyler et al., 2020). Motor competence is critical for children's development, shaping motor learning through physical and social interactions (Adolph & Hoch, 2019).

The potential link between motor competence and cognitive abilities has gained traction (van der Fels et al., 2015), yet research is limited (Albuquerque et al., 2022a; Fernández-Sánchez et al., 2022). Embodied cognition suggests cognitive development arises from sensory-motor interactions with the environment (Gibbs, 2005), reinforcing the idea that motor and cognitive skills are interconnected (Gandotra et al., 2022), yet empirical evidence remains scarce (Malambo et al., 2022).

Executive functions are a group of higher-order cognitive processes that form a multidimensional concept and support goal-directed behaviours and self-regulation (Diamond, 2000). While (Miyake et al., 2000) originally proposed a triadic model of the 'core executive functions' (working memory, inhibitory control, and cognitive flexibility), a broader framework including higher-order executive functions, such as planning, reasoning, and problem-solving (Lin et al., 2020), has now been highlighted (Best & Miller, 2010; Diamond, 2013). Executive functions can influence an individual's emotions, ideas, and actions, yet are only activated in goal-directed situations (Carlson et al., 2013; Huizinga et al., 2006). Thus, executive functions are crucial to necessitate effort to everyday tasks (Carlson et al., 2013;

Huizinga et al., 2006)The present study adopts a multidimensional perspective to demonstrate this developmental hierarchy, including five components: working memory, inhibition, cognitive flexibility, planning, and problem-solving. This approach recognises that middle childhood often highlights the integration of the core executive function components into higher-order executive function processes and thus should be included in future research on this population (Best & Miller, 2010; Diamond, 2013).

Executive functions develop rapidly during childhood, and extends throughout the lifespan, and have thus drawn interest (Diamond & Ling, 2016). In particular, the middle and late childhood periods are crucial for executive function development, since there are key changes in the development of the prefrontal cortex (Carlson et al., 2013) In combination, these processes can predict children's learning and successes, whilst providing a substantial foundation for children to absorb and process academic material (McClelland & Cameron, 2019). However, while some frameworks (Miyake et al., 2000) present executive functions as individual entities, others suggest a more unitary construct (Wiebe et al., 2008). Middle childhood presents a key transitional stage whereby executive functions begin to differentiate, yet inter-correlations among executive functions measures may remain high, therefore making it difficult to assess discrete executive functions (Carlson et al., 2013).

Few studies have examined motor competence-executive function associations within children (Albuquerque et al., 2022a; van der Fels et al., 2015), often using product-based measures like the KörperKoördinationsTest für Kinder (Kiphard & Schiling, 1974) or process-based measures such as the Test of Gross Motor Development Two/Three (Ulrich, 2000). The KörperKoördinationsTest für Kinder (Kiphard & Schiling, 1974) has been criticised in terms of the tendency to overestimate the number of individuals with motor coordination issues, and the comparison of data with standardised values may be outdated (Iivonen et al., 2015). Given that the KörperKoördinationsTest für Kinder (Kiphard & Schiling, 1974) is a product-orientated measure, there is no assessment of motor-skill quality, and thus would need to be combined with a process-based measure to provide a coherent assessment of MC (Ré et al., 2018). The Test of Gross Motor Development Two/Three (Ulrich, 2000) prevents motor skills to be modified to adjust to real-world contexts and instead are defined by environment-specific instructions (Hulteen et al., 2023). This assessment also fails to provide a holistic understanding of motor competence, since it abandons stability skills (Lopes et al., 2013a). The Test of Gross Motor Development Two/Three (Ulrich, 2000) has been highlighted for the lack of applicability across cultures, despite its suitability to assess a wide variety of motor skills (Hulteen et al., 2023). Therefore, these assessments focus on isolated skills (Ulrich, 2000) or either the or outcome of movements (Kiphard & Schiling, 1974), and thus warrants more comprehensive motor competence measures.

The Dragon Challenge (Tyler et al., 2018) encompasses both skill technique and outcome, yet to date, its use has been limited in motor competence research (Morley et al., 2021; Richards et al., 2023; Tyler et al., 2018, 2022). Most studies also overlook higher-order executive functions such as problem solving and planning (Fernández-Sánchez et al., 2022). The Tower of Hanoi (Byrnes et al., 1979), a key measure of these skills remains unexplored in motor competence research. Therefore, studies are needed to expand the understanding of the link between motor competence and higher-order executive functions.

Education is critical for an individual’s well-being, quality of life, and future (Farooq, 2011). Academic attainment alludes to the long-term impact on personal goals, career outlooks, and educational successes (Pizzolato et al., 2011). While physical activity’s link to academic attainment is well-documented (Ahamed et al., 2007; Fox et al., 2010; Rasberry et al., 2011), the motor competence-academic attainment association in primary school-aged children remains underexplored (Lopes et al., 2013b). Research suggests executive functions may mediate this association (Cadoret et al., 2018; Rigoli et al., 2012; Schmidt et al., 2017), as they are key predictors of academic attainment (Lopes et al., 2013a). The speed-accuracy trade-off is a common explanation for this, given that it is an essential component of both motor coordination and executive function tasks (Roebers & Kauer, 2009). The cognitive stimulation hypothesis (Best, 2010; Pesce, 2012a) and the skill acquisition approach (Tomporowski & Pesce, 2019) also highlight that cognitively challenging physical activity (that fosters motor competence) will engage the same brain regions for both learning and executive functions. However, few studies have investigated executive functions as mediators between motor competence and academic attainment in primary school-aged children (Cadoret et al., 2018; Rigoli et al., 2012; Schmidt et al., 2017).

Therefore, the current study aimed to 1) investigate associations between motor competence, executive functions, and academic attainment of 8-9-year-old children in England, and determine whether they differ between sex and deprivation groups and 2) examine whether greater motor competence has a positive impact on an individual's executive function (working memory, inhibitory control, cognitive flexibility, planning, and problem-solving) and academic attainment. It was hypothesised that (i) greater motor competence ability would be associated with higher performance on executive function tests and academic attainment, (ii) a positive indirect association would exist between motor competence and academic attainment through executive function, and (iii) higher executive function scores would be associated with greater academic attainment. Accordingly, this quantitative cross-sectional study was in partnership with 'Together an Active Future', a Sport England-funded Place-Based Partner for physical activity promotion in Pennine Lancashire, northwest England.

Method

Participants

Opportunity sampling recruited 247 participants (51.4% girls; age 8.7 ± .43 years; 77.7% white British; 5 ± 3.1 English Indices of Multiple Deprivation decile; 73.3% healthy weight) who were physically able to participate in physical activity, within Pennine Lancashire. Children aged 8-9 years were selected as this represents a key developmental window for executive functions and fundamental movement skills (Best & Miller, 2010;

Gallahue et al., 2012). This population also represents Key Stage 2 within the UK National Curriculum, of which presents increased demands across literacy and mathematics (Department for Education, 2013). This therefore requires enhanced attention regulation, problem solving (Best & Miller, 2010). The study of motor competence and executive function is particularly relevant for this population, since both domains undergo rapid development during this period (van der Fels et al., 2015). This study was ethically approved by the Edge Hill University Research Ethics Committee (REC- ETH2223-0207). Written informed consent was obtained from the School headteachers and the children's guardians. Written assent was obtained from the children, and the children were asked on the day of data collection whether they were happy to participate, ensuring verbal assent was also obtained. Children were made aware that they could withdraw at any time without penalty, and there was no pressure applied to participate. Participant's home postcode, ethnicity, and date of birth were obtained. Socio-economic status was determined via English Indices of Multiple Deprivation deciles (Ministry of Housing, Communities, and Local Government, 2019). The Indices of Multiple Deprivation deciles combine information from seven domains: income, employment, education, health and disability, crime, barriers to housing and services, and the living environment, to provide an overall score for each Lower-layer Super Output Area (Ministry of Housing, Communities, and Local Government, 2019). The Lower-layer Super Output Areas are then ranked and grouped into Deciles, whereby decile 1 represents the most deprived 10% of areas and Decile 10 represents the least deprived 10% (Ministry of Housing, Communities, and Local Government, 2019; Noble et al., 2006).

Anthropometric Data

Stature and body mass were measured to the nearest 0.1cm and 0.1kg following standardprocedures (Lohman et al., 1991), using a portable stadiometer and seca 761 digital scales (seca, Birmingham, UK), respectively. Body mass index and body mass index z-scores were calculated (Cole et al., 1995) and used to classify participants as normal, overweight, or obese according to the sex and age International Obesity Task Force BMI cut-off points (Cole, 2000).

Academic Attainment

National Curriculum attainment across reading, writing, and mathematics were categorised as (1) ‘working towards’ (a score of 80-99 - working below expected for their age), (2) ‘expected’ (a score of 100 - working at the expected level), and (3) ‘greater depth’ (a score of >110 - working above expected). This reflects the National Curriculum for key stage two scaled scores (Standards and Testing Agency, 2023). For analysis purposes, attainment for reading and writing were combined to form an overall literacy score.

Executive Functions

A battery of cognitive tests was administered online via the Psytoolkit software (version 3.4.6) (Stoet, 2010, 2017)- (https://www.psytoolkit.org/c/3.4.0/survey?s=B6JvP), on laptops/desktop computers, in which the lead researcher was adequately trained and competent in for use (Gilmour et al., 2023). Each executive function task was administered at a fixed difficulty and entry level, which remained consistent throughout the test and across all participants, regardless of performance.

Inhibition

The Eriksen Flanker Test (Eriksen & Eriksen, 1974) assessed inhibition. Five letters appeared on a blank screen. In congruent trials, all letters were identical, i.e., XXXXX, while in the incongruent trial, the middle letter differed, i.e., XXVXX. Participants pressed “A” if the centre letter was an X or C and “L” if it was a V or B. To familiarise participants, four practice trials (two congruent, two incongruent) were included. The test consisted of 25 trials (16 congruent, 9 incongruent) in pseudorandom order to minimise fatigue effects (Eriksen & Eriksen, 1974). The flanker effect was calculated by subtracting the average reaction time (ms) in congruent trials from incongruent trials. Reaction times <150ms were excluded to account for anticipatory responses (Bedard et al., 2021; Viviani et al., 2024). In instances where the mean incongruent and congruent reaction times were equal, resulting in a Flanker effect of zero, a value of 2000ms was imputed to reflect an invalid or atypical response, and to ensure consistency. This decision assumed that a zero difference in reaction times across conditions is unlikely to reflect true performance and therefore may result from an outlier behaviour or task disengagement. This test was implemented following a validation study for the Flanker test in children aged between 3-15-years (Zelazo et al., 2013). A higher flanker effect indicated weaker inhibition.

Visuospatial Working Memory

The Corsi-block test (Corsi, 1972) assessed visuospatial working memory as a valid and reliable measure (Siddi et al., 2020). This presents nine squares, with some illuminating in an increasing sequence per trial. Participants reproduced the sequence by clicking the squares in order. The test was terminated after three consecutive errors, and block-span was determined by the final correct sequence. To ensure this output aligned with the other executive function measures, the score was reversed, and thus a lower score represented a greater performance.

Cognitive Flexibility

The Wisconsin Card Sorting Task (Grant & Berg, 1948) assessed cognitive flexibility as this is the most used neurocognitive test of cognitive flexibility (Johnco et al., 2014; Tchanturia et al., 2012) and is widely accepted (Cragg & Chevalier, 2012; Figueroa & Youmans, 2013). Participants matched a response card to one of four multidimensional stimulus cards based on number, colour, or shape (Miles et al.). The matching rule changed after 10 consecutive correct responses, marking one ‘completed category’. The task ended after six categories or 60 trials. The total number of errors included perseveration (applying the old rule) and non-perseveration errors (Miles et al.). Fewer perseveration errors indicated greater cognitive flexibility.

Planning and Problem Solving

The Tower of Hanoi (Byrnes et al., 1979) is a multidimensional assessment that predominantly measured planning and problem solving, while also indicating working memory ability. This measure demonstrated high reliability through internal consistency (Humes et al., 1997). The participants were tasked to a set of disks, of varying size, across three pegs in the fewest moves possible (Mitani et al., 2022). Fewer moves indicated greater planning ability.

Motor Competence

The Dragon Challenge (Tyler et al., 2018) is a valid and reliable measure of motor competence (Tyler et al., 2018) and was administered and assessed in accordance with the Dragon Challenge manual (Tyler et al., 2018). The Dragon Challenge also requires children to illustrate movement skills and characteristics that are representative of an individual with a good level of physical competence and fitness (Tyler et al., 2018). The Dragon Challenge is a nine-station time trialled circuit of predominantly object-control (basketball dribbling, overarm throw, underarm throw and catch), stability (wobble sport, balance bench, core agility), and locomotor (jumping pattern, T-run, sprint) skills. The assessors achieved 90% agreement with an experienced Dragon Challenge assessor, prior to assessment in accordance with the Dragon Challenge manual (Tyler et al., 2018) . Performance was assessed through (1) time taken to complete the circuit, (2) three criterions (two technical (process) and one outcome (product)). Each construct, technique (scored out of 18), outcome (scored out of 9 multiplied by 2), and time (scored out of 18) provided an overall score out of 54. Time taken for participants to complete the Dragon Challenge was recorded in minutes and seconds, via a stopwatch, and converted to a score whereby a faster time receives a higher score. Time completion was recorded from the word ‘go’ and stopped when the participant crossed the finish line of the sprint task. The scoring calculation is available in the original studies (Tyler et al., 2018, 2020). Additionally, technique and outcome for each task were summed to provide Dragon Challenge cumulative task scores (Tyler et al., 2020).

Analysis

Descriptive statistics (mean and standard deviation) were calculated for all measured variables using SSPS/Amos software, v29 [IBM SPSS Statistics Inc., Chicago, IL, USA]. Little's missing completely at random test assessed the missing at random pattern of missing values. Data transformation included reversing the Corsi span (Corsi, 1972) score and converting Flanker scores (Eriksen & Eriksen, 1974) into absolute values, whereby a score of zero indicated the greatest performance.

A confirmatory factor analysis assessed the fit of two measured variables into three hypothesised latent variables: motor competence (Dragon Challenge cumulative task scores), executive function (Flanker effect, reversed Corsi-span, perseveration errors, Tower of Hanoi step count), and academic attainment (literacy and mathematics). Comparative fit index (CFI), Goodness of fit index (GFI), Incremental fit index (IFI), Root Mean Squared Error of Approximation (RMSEA; threshold of ≤ 0.08), and Standardised Root Mean Square Residual (SRMR; cut off value < 0.05) acted as criterion for good model fit, with CFI, GFI, and IFI >0.90 and RMSEA of <0.05 demonstrated good fit (Hu & Bentler, 1999). Structural equation modelling explored relationships between motor competence, executive function, and academic attainment, with direct effects assessed via path coefficients. An indirect effect was assessed by using the product of two direct effects between the three latent factors. Model fit was assessed again using CFI, GFI, IFI, AGFI, SRMR, and RMSEA fit indices (Hu & Bentler, 1999). A multi-group analysis (Chi-squared difference test) examined moderation by sex (boys vs. girls), weight status (healthy weight vs. overweight), and deprivation (low-medium deprivation (decile ≥ 6) vs. medium-high deprivation (decile ≤ 5)). Non-significant paths were removed from the final structural equation model.

Results

Descriptive statistics of the final analytical sample are provided in table 1. The final sample included 247 children (51.4% girls), with a mean age of 8.7 ± 0.4 years. The average Indices of Multiple Deprivation (IMD) decile was 5.0 ± 3.1, indicating a broad socioeconomic distribution. The majority of participants were of white British ethnicity (77.7%), and 26.7% were classified as overweight. The overall Dragon Challenge average score was 30.2 ± 7.8. executive function scores indicated considerable variability, particularly in the Flanker effect (76.8 ± 231.7ms). Literacy and mathematics attainment were within the expected range for the sample's age. The rate of missingness ranged from 0% (age, sex and ethnicity) to 6% (number of wobble spot passes). Little's missing completely at random test was administered (χ^2 = 254.9, df= 722, *p*= 1.00). Overall, 1.5% of the data were missing completely at random. The median scores for the Dragon Challenge were imputed for the missing values and multiple imputation was used for all continuous variables (Schafer, 1999; Sterne et al., 2009).

Table 1 Descriptive Characteristics of the participants (M (SD) unless indicated otherwise).

Variables	**All**	**Sex**	
		Boys	**Girls**
n	247	120	127
Age (years)	8.7 (0.4)	8.7 (0.4)	8.7 (0.4)
Girls *n* (%)	127 (51.4)	-	-
Boys *n* (%)	120 (48.6)	-	-
Indices of Multiple Deprivation decile	5.02 (3.1)	4.8 (3.1)	5.2 (3.1)
Ethnicity *n* (%)			
White British	192 (77.7)	95 (79.2)	97 (76.4)
Asian	6 (2.4)	5 (4.2)	1 (0.8)
Mixed	9 (3.6)	3 (2.5)	6 (4.7)
Other White	1 (0.4)	0 (0)	1 (0.8)
Pakistani	35 (14.2)	14 (11.7)	21 (16.5)
Bangladeshi	2 (0.8)	2 (1.7)	0 (0)
Indian	1 (0.4)	1 (0.8)	0 (0)
Other	1 (0.4)	0 (0)	1 (0.8)
Weight Status *n* (%)			
Healthy Weight	181 (73.3)	92 (76.7)	89 (70.1)
Overweight	66 (26.7)	28 (23.3)	38 (29.9)
Motor Competence			
Balance Bench (0-4)	2.2 (1.6)	2.2 (1.7)	2.3 (1.6)
Core Agility (0-4)	2.0 (1.5)	1.6 (1.4)	2.3 (1.5)
Wobble Spot (0-4)	1.7 (2.0)	3.1 (0.9)	1.9 (2.0)

Overarm Throw (0-4)	2.1 (1.2)	2.3 (1.3)	1.9 (1.1)
Basketball Dribble (0-4)	1.3 (1.6)	1.9 (1.7)	0.8 (1.2)
Catch (0-4)	1.5 (1.6)	1.8 (1.6)	1.1 (1.3)
T-agility (0-4)	2.2 (1.4)	2.2 (1.3)	2.2 (1.5)
Jumping Patterns (0-4)	2.4 (1.6)	2.2 (1.7)	2.6 (1.6)
Sprint (0-4)	3.0 (0.9)	3.1 (0.9)	3.0 (0.9)
Process Score	9.3 (3.6)	9.5 (3.7)	9.0 (3.5)
Product Score	9.2 (3.6)	9.5 (3.6)	9.0 (3.6)
Time Score	11.8 (2.1)	12.2 (2.4)	11.4 (1.8)
Overall Dragon Challenge score	30.2 (7.8)	30.9 (8.1)	29.4 (7.4)
Executive Function			
Flanker Effect (seconds)	76.8 (231.7)	43.7 (242.4)	108.0 (217.5)
Corsi-Span	3.2 (2.0)	3.1 (2.0)	3.2 (1.9)
Wisconsin Card Sorting Task Perseveration Error Count	14.4 (4.2)	14.5 (4.1)	14.3 (4.2)
Tower of Hanoi Steps Taken	18.4 (9.3)	19.4 (9.5)	17.5 (9.0)
Academic Attainment			
Literacy Attainment (2-6)	3.7 (1.2)	3.6 (1.2)	3.8 (1.3)
Mathematics Attainment (1-3)	2.0 (0.7)	2.0 (0.7)	1.9 (0.7)

Associations between three latent variables (motor competence, executive function, and academic attainment) and their indicators were examined via a three-factor measurement model via confirmatory factor analysis. After the addition of four correlations between.

The confirmatory factor analysis unstandardised beta values indicate that the Flanker effect ($\lambda = -0.63$, SE = 8.5, $p = 0.48$) did not significantly contribute to the executive function latent variable and was removed. The chi-square difference test indicated no significant difference between models ($\Delta\chi^2 = 30.4$, $\Delta df = 26$, $p > 0.05$), but removing the Flanker effect improved model fit (CFI, 0.96; GFI, 0.95; IFI, 0.96; AGFI, 0.93; SRMR, 0.05; RMSEA, 0.03) (Figure 1).

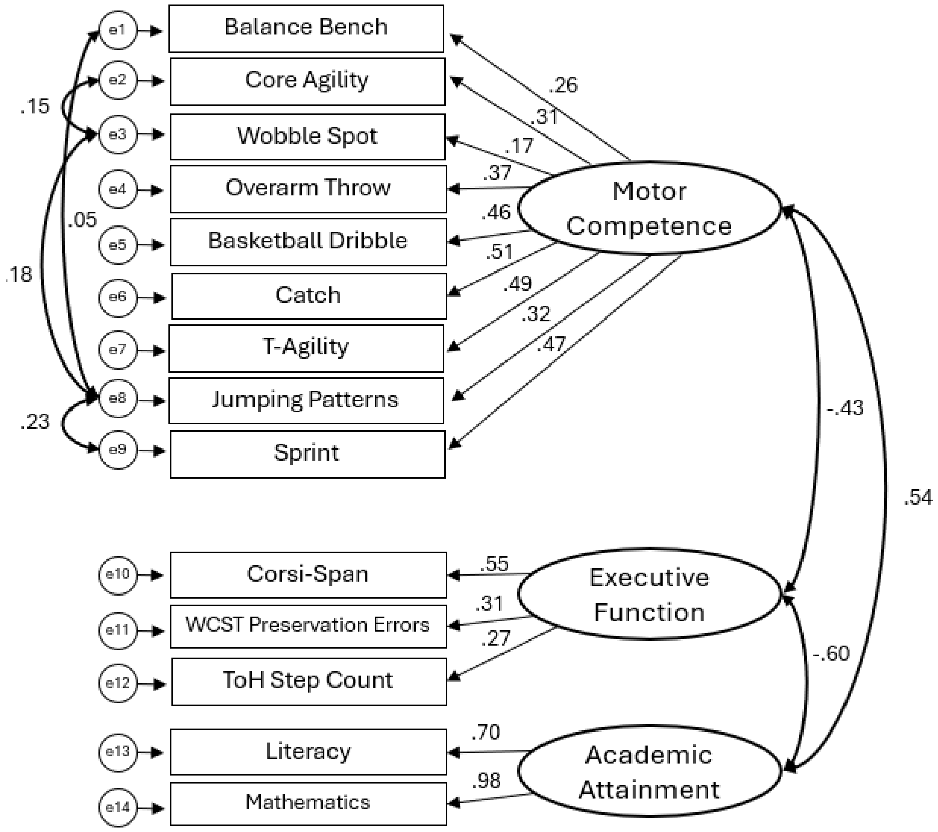


Figure 1- Final Confirmatory Factor Analysis of the measured variables into three hypothesised latent factors

The hypothesised structural equation model revealed a significant chi-square value of χ^2 (84) = 218.637, p <0.01, indicating a good model fit. A further assessment of model fit revealed CFI, 0.70; GFI, 0.87; IFI, 0.72; AGFI, 0.82; SRMR, 0.10; RMSEA, 0.08, which also highlighted poor to adequate model fit.

Prior to further analyses, intraclass correlation coefficients were calculated to account for school nesting. These results highlighted minimal statistical dependency within school clusters (< 0.1), indicating that majority of the variance is attributed to the participants.

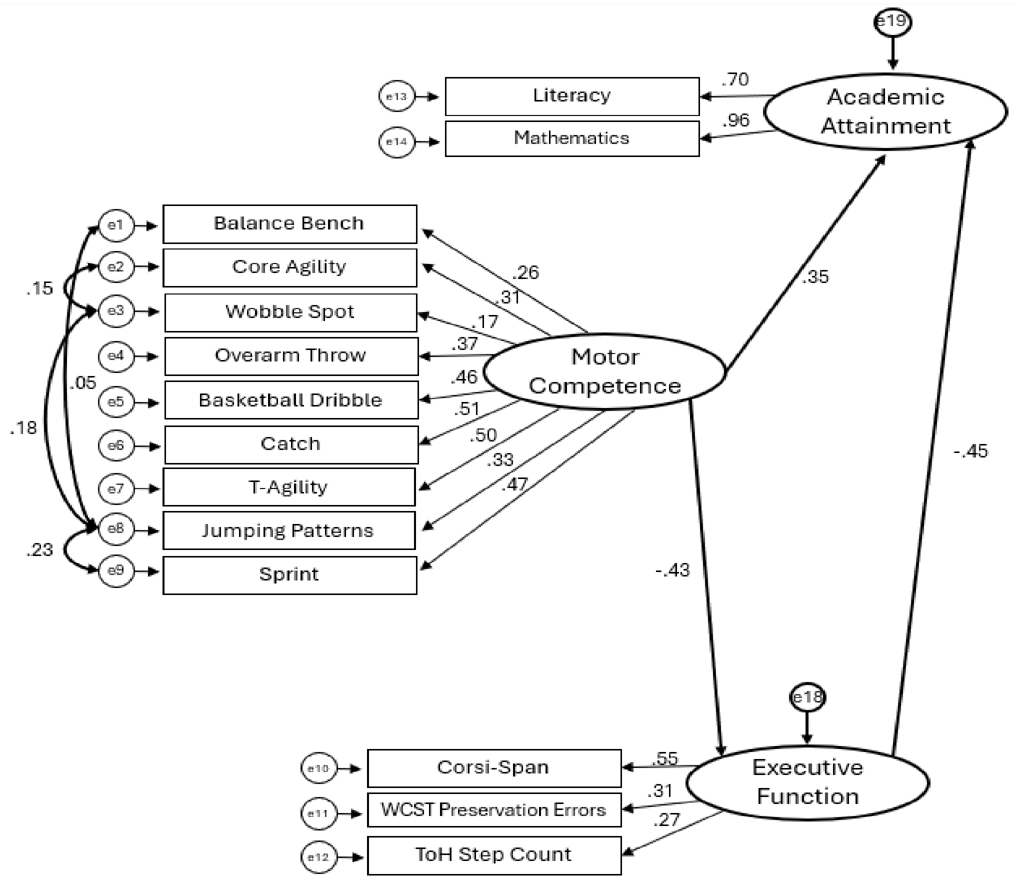


Figure 2- Final SEM evaluating relationships between motor competence, executive function, and academic attainment

The final structural equation model (figure 2) highlights the standardised beta values, and an excellent model fit on a global level ($\chi^2(70) = 88.652$, $p = 0.07$; CFI, 0.96; GFI, 0.95; IFI, 0.06; AGFI, 0.93; SRMR, 0.05; RMSEA, 0.03), indicating a significant improvement in model fit. A chi-square difference test confirmed this improvement ($\Delta\chi^2 = 129.9$, $\Delta df = 14$, $p < 0.05$). Overall, the fit indices highlight that the final structural equation model fits the data well.

The unstandardised beta values of this model demonstrated a negative direct effect of motor competence on executive function ($\beta = -2.55$, 95% CI [-4.87, -0.24]), indicating that higher motor competence performance was associated with lower executive function scores (more efficient executive function abilities). Motor competence was also significantly associated with academic attainment (β= 0.57, 95% CI [0.16, 0.98]). An indirect association between motor competence and academic attainment, mediated by executive function, was found (β= 0.20, *p* = 0.01), demonstrating that motor competence's association with academic attainment was partly explained by its influence on executive function. Finally, the direct effect of executive function on academic attainment was negative (β= -0.13,95% CI [-0.24, -0.02]), which revealed that better executive function (lower scores) were associated with higher academic attainment.

There was no significant difference in models and paths for sex (*p* = 0.38) and weight status (*p* = 1.00). However, a significant difference was found for deprivation (*p* = 0.03), and for the path between motor competence and academic attainment (*p* = 0.04).

The final structural equation model for deprivation groups revealed an excellent model fit for individuals within low-medium deprivation areas (see supplementary material S1) ($\chi^2(70)$ = 70.448, *p* = 0.46; CFI, 1.00; GFI, 0.91; IFI, 1.00; AGFI, 0.87; SRMR, 0.07; RMSEA, 0.01). A significant positive direct effect of motor competence on academic attainment was found (β= 1.15,95% CI [0.29, 2.01]), yet the paths between motor competence and executive function (β= -0.25,95% CI [-1.35, 0.85]) and between executive function and academic attainment (β= -0.18,95% CI [-0.79, 0.43]) were not significant. The indirect path between motor competence and academic attainment, mediated by executive function, presented a significant association (β= .021, *p* = 0.01).

The final structural equation model revealed a good model fit for individuals within high-medium deprivation areas (supplementary material S2) ($\chi^2(70)$ = 88.031, *p* = 0.07; CFI, 0.94; GFI, 0.92; IFI, 0.94; AGFI, 0.88; SRMR, 0.06; RMSEA, 0.04). A significant direct negative effect was highlighted for the motor competence-executive function path (motor competence was associated with better executive function (lower scores)) (β +6= -4.43,95% CI [2.55, 9.45]), yet the paths between motor competence and academic attainment (β= -1.00,95% CI [-2.23, 0.23]) and executive function and academic attainment (β= -0.21,95% CI [-0.48, 0.06]) were not significant. The indirect path between motor competence and academic attainment, mediated by executive function, was also not significant (β= 0.63, *p* = 0.88).

Discussion

This novel study is amongst the first to report the direct and indirect relationships between motor competence, executive function, and academic attainment in 8-9-year-old children using path analyses. The confirmatory factor analysis demonstrates that the fit of the measured variables into three hypothesised latent factors was good, highlighting that the measures in this study were positively associated with the given latent factors. The final structural equation model displayed significant associations between motor competence, executive function, and academic attainment, and thus the interconnectedness between the motor and cognitive domains within primary school-aged children within England.

The association between motor competence and executive function observed in this study aligns with previous findings (Cook et al., 2019a; Fernández-Sánchez et al., 2022; Gandotra et al., 2022; Oberer et al., 2018; Piek et al., 2008), and is supported by a recent systematic review (Bao et al., 2024), and the findings of this study. However, there are inconsistencies within this area. For instance, (van der Veer et al., 2024) reported no significant association in a younger sample (three-five-years), using the Movement Assessment Battery for Children-Second Edition (MABC-2) (Henderson et al., 2010). This is a tool that primarily assesses static motor skills, and so fails to capture motor competence in dynamic, ecological tasks, which often impose greater cognitive load, task complexity and executive function demands (Carlson et al., 2013; Diamond, 2000; Ludyga et al., 2019; Wilson et al., 2013). This may partially explain the mixed findings across existing literature. For example, (Albuquerque et al., 2022a) implemented the KörperKoördinationsTest für Kinder (Kiphard & Schiling, 1974) and the Test of Gross Motor Development Two (Ulrich, 2000), which does not consider stability skills (Lopes et al., 2013b), while (Davis et al., 2011) implemented the Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition (Bruininks & Bruininks, 2012), which emphasises fine motor skills but lacks ecological validity (Larkin &

Cermack, 2002). Therefore, such variations in motor competence measures and a wider age range, than that of this study, complicate direct comparison across studies.

Furthermore, while this study has acknowledged the heterogeneity of motor competence assessments, it is also important to consider the variability in executive function measurements across existing literature. Previous studies that have explored the association between motor competence and executive function (Albuquerque et al., 2022b; Cook et al., 2019a; Davis et al., 2011; Fernández-Sánchez et al., 2022; Gandotra et al., 2022; Oberer et al., 2018; Piek et al., 2008) have employed a range of executive function tasks that target different domains and utilised various scoring systems, task complexity, and administrative protocols. There is potential for the lack of consistency in executive function measurement to partially explain the mixed findings across existing studies, as well as individual differences in general processing playing a role (Löffler et al., 2024). Thus, future research should consider standardised, multi-domain EF batteries that also present strong psychometric properties (Löffler et al., 2024).

Moreover, the strength of the association between motor competence and executive function may be influenced by the motor competence assessment implemented. For example, the Dragon Challenge (Tyler et al., 2018, 2020) is a more ecologically valid and dynamic assessment of motor competence and therefore is more likely to engage executive function processes more directly than static or narrowly focused assessments (Kiphard & Schiling, 1974; Ulrich, 2000). Motor skill tasks that incorporate multiple domains, such as utilising locomotor, stability, and object control skills together (Tyler et al., 2018, 2020), will also require children to utilise executive functions to plan, inhibit, and adapt their movements (Tomporowski & Pesce, 2019). Increasing the coordinative and cognitive complexity of a task, through manipulation of environmental and task constraints, reflects a stronger association between executive function and its neural substrate activity (Ludyga et al., 2019). By contrast, static motor competence assessments, such as the MABC-2, may not accurately represent these cognitive-motor interactions (Henderson et al., 2010). In addition to the methodological limitations of the MABC-2(Henderson et al., 2010), age-related executive function development may also explain the lack of association in young children. Executive functions develop rapidly during the early school years (Li et al., 2020), yet performance on executive function tasks does not mature until adolescence (Li et al., 2020). It is thus possible that developmental variability may alter associations that stabilise as children grow older and their executive function skills consolidate. Therefore, when exploring cognitive-motor associations, it is crucial to consider that task complexity may enhance this association by inherently involving executive functions, and that executive function development may play a crucial role.

Additionally, the Dragon Challenge (Tyler et al., 2018, 2020) may also provide insight into physical fitness, especially speed, muscular strength/endurance, and cardiovascular endurance, particularly within the core agility, jumping, and sprinting tasks, as well as, running back to the tablet between each task (Ortega et al., 2008). It could therefore be suggested that overall physical fitness may play a key role in the participants performance in the Dragon Challenge tasks (Stodden et al., 2008). Nonetheless, the Dragon Challenge does include both process-orientated and product-orientated criteria, based upon developmentally appropriate motor skills, which supports a broader image of motor competence ability. The overall Dragon Challenge score reflects a multitude of domains, such as stability, locomotor, object control, and timing) (Tyler et al., 2018, 2020), which takes the focus away from any single component. Motor competence and physical fitness are distinctive concepts, yet are interrelated, and thus children with stronger physical fitness may obtain higher motor competence scores (Robinson et al., 2015). This suggests that the Dragon Challenge (Tyler et al., 2018, 2020) may capture a combined profile of both motor competence abilities and levels of physical fitness. Perhaps future research should consider the role of physical fitness levels when conducting assessments of motor competence abilities to control for their potential influence on motor competence scores.

Deprivation is an environmental constraint, which typically accounts for parental education, occupation, and income (Cook et al., 2019b), that may influence the motor competence-executive function relationship (Chang & Gu, 2018; Piek et al., 2008). The ecological dynamics perspective (Button et al., 2021) purports that motor and cognitive development occur simultaneously. The environment is said to play a crucial role within this association, given that access to key resources, physical activity and educational opportunities can be restricted (Ghorbanzadeh et al., 2025). Individuals within less deprived areas often have access to greater facilities and structured physical activities, which allow for the enhancement and development of motor competence and executive functions (Barnett et al., 2016). The ecological dynamics perspective therefore underscores how these constraints may work cooperatively, framing developmental pathways and establishing how motor and cognitive skills may coexist among varying socio-cultural environments (Ghorbanzadeh et al., 2025). The final structural equation model supports this, demonstrating a significant direct effect of motor competence on executive function in medium-high deprivation areas. However, no studies using structural equation model have compared this association across different deprivation groups, rather studies have only considered the role of deprivation (Aadland, Katrine Nyvoll et al., 2017; Ghorbanzadeh et al., 2025; O'Callaghan et al., 2024), and thus a valuable future implication is highlighted.

The structural equation model revealed a significant direct effect of motor competence on academic attainment, whereby greater motor competence performances are associated with higher academic attainment. This aligns with latent approach studies (de Bruijn et al., 2019; Lopes et al., 2013b; Rigoli et al., 2012; van der Niet et al., 2014) and wider analyses (Batez et al., 2021; Guillamón et al., 2021; Vanhala et al., 2023). This underscores the importance of developing children’s motor competence to support educational success’ (Vanhala et al., 2023), and thus may inform intervention strategies for educators and policymakers (de Greeff et al., 2018; Oberer et al., 2018).

A significant direct path between motor competence and academic attainment was found in the low-medium deprivation group, but not in medium-highly deprived areas, which is consistent with previous studies (Morley et al., 2015). This implies that in less deprived areas, greater motor competence abilities are associated with higher academic attainment. Children from low socio-economic areas often face limited movement skill development opportunities, which may contribute to weaker academic attainment (Anders et al., 2012; Morley et al., 2015). No previous studies have examined motor competence-academic attainment associations across deprivation groups. Education professionals should encourage movement skill development, and further research on socio-economic-related impacts on motor competence and academic attainment is warranted.

Beyond neurophysiological explanations for the motor competence-academic attainment relationship (Khan & Hillman, 2014; Stillman et al., 2016), research now emphasises psychological mediators over exercise-related mechanisms (Pesce, 2012b). Executive function is a frequently cited mediator, often explained by the speed-accuracy trade-off essential in both motor coordination and executive function tasks (Roebers & Kauer, 2009). The finding of a significant indirect effect of motor competence on academic attainment via executive function supports this, aligning with other studies (Fernández-Sánchez et al., 2022; Piek et al., 2008; Vanhala et al., 2023). Executive function has been found to mediate the motor competence-academic attainment relation in 10- to 12-year-olds (Schmidt et al., 2017), and in 12- to 16-year-olds (Rigoli et al., 2012), reinforcing that stronger motor competence is associated with better executive function, ultimately enhancing academic attainment.

The final structural equation model revealed a significant direct effect of executive function on academic attainment, indicating that stronger executive function is associated with academic success in primary school children, aligning with cross-sectional studies (Gathercole, S. E. et al., 2003; Gathercole, Susan E. et al., 2004). The final structural equation model included three executive function tasks, Wisconsin Card Sorting Task (Grant

& Berg, 1948), Corsi-span Task (Corsi, 1972), and the Tower of Hanoi (Byrnes et al., 1979) to form the latent executive function variable, highlighting that executive functions contribute to mathematics (Bull & Scerif, 2001) and literacy (Yeniad et al., 2013) achievement. This aligns with other studies (St Clair-Thompson & Gathercole, 2006) who used a latent approach to assess executive function and academic attainment in 11–12-year-olds. Despite a small sample (n = 51), they examined core executive functions (working memory, inhibition, cognitive flexibility) (St Clair-Thompson & Gathercole, 2006), unlike the current study, which excluded the Flanker task (Eriksen & Eriksen, 1974) due to non-significance. While a small sample size limits statistical power (Kyriazos, 2018), this study also did not assess higher-order executive functions (St Clair-Thompson & Gathercole, 2006). Thus, the multifaceted approach of the current study offers more understanding of cognitive contributions to academic attainment.

The association between executive function and academic attainment did not vary significantly across deprivation groups, suggesting that executive function’s direct effect on academic attainment remains consistent regardless of socio-economic status. Other factors may mediate this relationship, such as self-control (Duckworth et al., 2019), school organization and teaching methods (Vermunt & Endedijk, 2011), and self-motivation (Zeegers, 2001). The complexity of cognition’s role in educational outcomes may explain why some studies support executive function’s positive influence on academic attainment (Gathercole, Susan E. et al., 2004; Yeniad et al., 2013), while others do not (Mayes et al., 2009). Although executive function is a predictor of academic attainment, it is unclear whether early academic attainment also influences executive function development (Fuhs et al., 2014; Welsh et al., 2010), suggesting a possible bidirectional relationship (Fuhs et al., 2014). Further research is needed to explore additional mediating factors.

Strengths and Limitations

This study demonstrated numerous strengths that warrant discussion. The equal gender representation (49% male and 51% female) enhances generalisability (Babbie, 2013). The structural equation model accounted for measurement error, ensuring precise associations between latent factors (Kline, 2023). Implementation of the Dragon Challenge (Tyler et al., 2018) to measure motor competence provided a comprehensive understanding of children's motor skills and their link to executive function. Core and higher-order executive functions formed a single latent executive function variable, while only one previous study (Fernández-Sánchez et al., 2022) incorporated higher-order executive functions when examining associations with motor competence. The confirmatory factory analysis revealed the significance of higher-order executive function measures, offering deeper insights into motor competence's influence on both core and higher-order executive functions, paving the way for future research.

However, this study is not without limitations. The cross-sectional design limits the inference of causal relationships between the variables. The sample was ethnically homogeneous (78% White British), limiting the generalisability to children from other ethnic backgrounds, although this is representative of the ethnic distribution in England and the United Kingdom. Implementing structural equation modelling to explore complex associations requires a large sample size (Kyriazos, 2018). A sample size of 200-299 is considered "fair" for structural equation modelling (Comrey et al., 1973). For multi-group analysis, a minimum of 100 participants per group is recommended (Kline, 2016), yet the final structural equation model could not be examined between ethnic groups due to limited ethnic representation. The current study included very few indicators for academic attainment (two) and executive function (four), yet small sample sizes with fewer indicators per latent variable can lead to improper solutions in structural equation modelling (Kline, 2016).

Currently, limited executive function tests for children exist (Anderson, 2001), and often lack standardised administrative and scoring procedures (Anderson, 2001). This warrants traditional executive function tests to be normed for children. The Flanker task (Eriksen & Eriksen, 1974) did not significantly represent executive function in 8- to 9-year-old children. As the five-letter Flanker is not widely used in children, it may be more cognitively demanding than the arrow Flanker (Richard Ridderinkhof et al.) or fish Flanker (Zelazo et al., 2013), which may be more appropriate. The current study provided four practice trials, yet other studies (Albuquerque et al., 2022b; Zelazo et al., 2013) have implemented a more beneficial criterion-based approach. In these studies, 75% accuracy on practice trials was required (Davidson et al., 2006) before proceeding to the test block. Participants could receive additional practice blocks, but the test would be terminated if the criteria were still not met (Zelazo et al., 2013). Future research should consider these practices, to enhance instruction and test performance (Collie et al., 2003). The Psytoolkit software (Stoet, 2010, 2017) used for the executive function tests also had limitations with its user friendliness. Therefore, future research should explore alternative platforms, such as The Cambridge Neuropsychological Test Automated Battery (Cambridge Cognition, 1996).

Conclusion

This study offers a comprehensive understanding of how children’s motor and cognitive skills can intertwine to support academic achievement. This study adds depth to the motor-cognition phenomenon, broadening executive function research by examining motor competence’s role in cognition. These findings emphasise the multifaceted nature of child development and the need for a holistic educational approach to integrating directed physical activity to improve motor skills, and cognitive training. Educators and policymakers should prioritise motor competence/development by incorporating structured physical activity into daily school routines and supporting teacher training in motor skill development. Embedding motor competence into education policy may enhance both physical and academic outcomes. Future research should explore these relationships longitudinally and consider mediating factors, such as mental health, socioeconomic status, and sleep quality to further unravel the motor-cognition phenomenon.

Acknowledgements: The authors would like to express their gratitude to the children and schools who participated in the project. We would also like to thank the middle leaders and staff for assisting with participant recruitment and data collection.

Funding: This study was funded by Together an Active Future. The funding body had no role in the design of the study, the collection, analysis and interpretation of data, or the writing of the manuscript.

Author Contributions:

Ayva-Mae Gilmour: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Data curation, Writing- Original draft preparation, Visualization, Project administration

Mhairi J. MacDonald: Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing- Reviewing and Editing, Supervision

Lauren Clifford: Methodology, Validation, Investigation, Resources, Data curation, Writing- Reviewing and Editing, Project administration

Stuart J. Fairclough: Conceptualization, Methodology, Validation, Investigation, Resources, Data curation, Writing- Reviewing and Editing, Supervision

Jordan Banks: Investigation, Resources, Data curation, Writing- Reviewing and Editing, Project administration

Peter Edwards: Investigation, Resources, Data curation, Writing- Reviewing and Editing, Project administration

Richard Tyler: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Data curation, Writing- Reviewing and Editing, Visualization, Supervision

References

Aadland, K. N., Ommundsen, Y., Aadland, E., Brønnick, K. S., Lervåg, A., Resaland, G. K., & Moe, V. F. (2017). Executive functions do not mediate prospective relations between indices of physical activity and academic performance: The Active Smarter Kids (ASK) study. *Frontiers in Psychology, 8*(JUN)10.3389/fpsyg.2017.01088

Aadland, K. N., Moe, V. F., Aadland, E., Anderssen, S. A., Resaland, G. K., & Ommundsen, Y. (2017). Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children. *Mental Health and Physical Activity, 12*, 10–18. 10.1016/j.mhpa.2017.01.001

Abdin, S., Welch, R. K., Byron-Daniel, J., & Meyrick, J. (2018). The effectiveness of physical activity interventions in improving well-being across office-based workplace settings: a systematic review. *Public Health, 160*, 70–76. 10.1016/j.puhe.2018.03.029

Adamson, B. C., Ensari, I., & Motl, R. W. (2015). Effect of Exercise on Depressive Symptoms in Adults With Neurologic Disorders: A Systematic Review and Meta-Analysis. *Archives of Physical Medicine and Rehabilitation, 96*(7), 1329–1338. 10.1016/j.apmr.2015.01.005

Adolph, K. E., & Hoch, J. E. (2019). Motor Development: Embodied, Embedded, Enculturated, and Enabling. *Annual Review of Psychology, 70*(1), 141–164. 10.1146/annurev-psych-010418-102836

Adsett, J. A., Mudge, A. M., Morris, N., Kuys, S., & Paratz, J. D. (2015). Aquatic exercise training and stable heart failure: A systematic review and meta-analysis. *International Journal of Cardiology, 186*, 22–28. 10.1016/j.ijcard.2015.03.095

Ahamed, Y., Macdonald, H., Reed, K., Naylor, P., Liu-Ambrose, T., & Mckay, H. (2007). School-Based Physical Activity Does Not Compromise Children's Academic Performance. *Medicine & Science in Sports & Exercise, 39*(2), 371–376. 10.1249/01.mss.0000241654.45500.8e

Albuquerque, M. R., Rennó, G. V. C., Bruzi, A. T., Fortes, L. d. S., & Malloy-Diniz, L. F. (2022a). Association between motor competence and executive functions in children. *Applied Neuropsychology: Child, 11*(3), 495–503. 10.1080/21622965.2021.1897814

Albuquerque, M. R., Rennó, G. V. C., Bruzi, A. T., Fortes, L. d. S., & Malloy-Diniz, L. F. (2022b). Association between motor competence and executive functions in children. *Applied Neuropsychology: Child, 11*(3), 495–503. 10.1080/21622965.2021.1897814

Anders, Y., Rossbach, H., Weinert, S., Ebert, S., Kuger, S., Lehrl, S., & von Maurice, J. (2012). Home and preschool learning environments and their relations to the development of early numeracy skills. *Early Childhood Research Quarterly, 27*(2), 231–244. 10.1016/j.ecresq.2011.08.003

Anderson, V. (2001). Assessing executive functions in children: biological, psychological, and developmental considerations. *Pediatric Rehabilitation, 4*(3), 119. 10.1080/13638490110091347

BABBIE, E. R. (2013). *The practice of social research* (13th ed.). Wadsworth Cengage Learning.

Bao, R., Wade, L., Leahy, A. A., Owen, K. B., Hillman, C. H., Jaakkola, T., & Lubans, D. R. (2024). *Associations Between Motor Competence and Executive Functions in Children and Adolescents: A Systematic Review and Meta-analysis*. Springer Science and Business Media Deutschland GmbH. 10.1007/s40279-024-02040-1

Barnett, L. M., Lai, S. K., Veldman, S. L. C., Hardy, L. L., Cliff, D. P., Morgan, P. J., Zask, A., Lubans, D. R., Shultz, S. P., Ridgers, N. D., Rush, E., Brown, H. L., & Okely, A. D. (2016). Correlates of Gross Motor Competence in Children and Adolescents: A Systematic Review and Meta-Analysis. *Sports Medicine, 46*(11), 1663–1688. 10.1007/s40279-016-0495-z

Batez, M., Milošević, Ž, Mikulić, I., Sporiš, G., Mačak, D., & Trajković, N. (2021). Relationship between Motor Competence, Physical Fitness, and Academic Achievement in Young School-Aged Children. *BioMed Research International, 2021*, 1–7. 10.1155/2021/6631365

Bedard, C., Bremer, E., Graham, J. D., Chirico, D., & Cairney, J. (2021). Examining the Effects of Acute Cognitively Engaging Physical Activity on Cognition in Children. *Frontiers in Psychology, 12*10.3389/fpsyg.2021.653133

Best, J. R. (2010). Effects of physical activity on children’s executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331–351.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*(6), 1641–1660. 10.1111/j.1467-8624.2010.01499.x

Bouchard, C., Blair, S. N., & Haskell, W. L. (2007). Why Study Physical Activity and Health. In C. BOUCHARD, S. N. BLAIR & W. L. HASKELL (Eds.), *Physical Activity and Health* (pp. 3–19). Human Kinetics.

Bruininks, R. H., & Bruininks, B. D. (2012). *Bruininks-Oseretsky Test of Motor Proficiency, Second Edition*10.1037/t14991-000

Bull, R., & Scerif, G. (2001). Executive Functioning as a Predictor of Children's Mathematics Ability: Inhibition, Switching, and Working Memory. *Developmental Neuropsychology, 19*(3), 273–293. 10.1207/S15326942DN1903_3

Button, C., Seifert, L., Chow, J. Y., Araújo, D., & Davids, K. (2021). *Dynamics of skill acquisition: An ecological dynamics approach*. Human Kinetics Publishers.

Byrnes, M. M., Spitz, H. H., Johnstone, E. R., Anghelone, J., Buerman, P., Combs, V., Cox, H., Craib, S., Dougherty, R., Martin, M., Mcfrye, R., Murphy, M., Nachtsheim, N., Thom, E., & Wallender, J. (1979). *Developmental progression of performance on the Tower of Hanoi problem.* (No. 14).Simon.

Cadoret, G., Bigras, N., Duval, S., Lemay, L., Tremblay, T., & Lemire, J. (2018). The mediating role of cognitive ability on the relationship between motor proficiency and early academic achievement in children. *Human Movement Science, 57*, 149–157. 10.1016/j.humov.2017.12.002

Cambridge Cognition. (1996). Cambridge Neuropsychological Test Automated Battery [computer software]. Cambridge: Cambridge Cognition Ltd.

Carlson, S. M., Zelazo, P. D., & Faja, S. (2013). Executive Function. In P. D. ZELAZO (Ed.), *The oxford handbook of developmental psychology* (pp. 706–743). Oxford University Press.

Chang, M., & Gu, X. (2018). The role of executive function in linking fundamental motor skills and reading proficiency in socioeconomically disadvantaged kindergarteners. *Learning and Individual Differences, 61*, 250–255.

Cole, T. J. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ, 320*(7244), 1240–1240. 10.1136/bmj.320.7244.1240

Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference curves for the UK, 1990. *Archives of Disease in Childhood, 73*(1), 25–29. 10.1136/adc.73.1.25

Collie, A., Maruff, P., Darby, D. G., & Mcstephen, M. (2003). The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test–retest intervals. *Journal of the International Neuropsychological Society, 9*(3), 419–428. 10.1017/S1355617703930074

Comrey, A. L., Backer, T. E., & Glaser, E. M. (1973). *A Sourcebook for Mental Health Measures*. Human Interaction Research Institution.

Cook, C. J., Howard, S. J., Scerif, G., Twine, R., Kahn, K., Norris, S. A., & Draper, C. E. (2019a). Associations of physical activity and gross motor skills with executive function in preschool children from low-income South African settings. *Developmental Science, 22*(5)10.1111/desc.12820

Cook, C. J., Howard, S. J., Scerif, G., Twine, R., Kahn, K., Norris, S. A., & Draper, C. E. (2019b). Associations of physical activity and gross motor skills with executive function in preschool children from low-income South African settings. *Developmental Science, 22*(5), e12820.

Corsi, P. (1972). *Memory and the Medial Temporal Region of the Brain*

Cragg, L., & Chevalier, N. (2012). The processes underlying flexibility in childhood. *Quarterly Journal of Experimental Psychology, 65*(2), 209–232. 10.1080/17470210903204618

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037–2078. 10.1016/j.neuropsychologia.2006.02.006

Davis, E. E., Pitchford, N. J., & Limback, E. (2011). The interrelation between cognitive and motor development in typically developing children aged 4-11 years is underpinned by visual processing and fine manual control. *British Journal of Psychology, 102*(3), 569–584. 10.1111/j.2044-8295.2011.02018.x

de Bruijn, A. G. M., Kostons, D. D. N. M., van der Fels, I. M. J., Visscher, C., Oosterlaan, J., Hartman, E., & Bosker, R. J. (2019). Importance of aerobic fitness and fundamental motor skills for academic achievement. *Psychology of Sport and Exercise, 43*, 200–209. 10.1016/j.psychsport.2019.02.011

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of Science and Medicine in Sport, 21*(5), 501–507. 10.1016/j.jsams.2017.09.595

Department for Education. (2013). The national curriculum in

England
Key stages 1 and 2 framework document.

Diamond, A. (2000). Close Interrelation of Motor Development and Cognitive Development and of the Cerebellum and Prefrontal Cortex. *Child Development, 71*(1), 44–56. 10.1111/1467-8624.00117

Diamond, A. (2013). *Executive functions*. Annual Reviews Inc. 10.1146/annurev-psych-113011-143750

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18*, 34–48. 10.1016/j.dcn.2015.11.005

Duckworth, A. L., Taxer, J. L., Eskreis-Winkler, L., Galla, B. M., & Gross, J. J. (2019). *Self-Control and Academic Achievement*10.1146/annurev-psych-010418-

Eriksen, B., & Eriksen, C. W. (1974). *Effects of noise letters upon the identification of a target letter in a nonsearch task*.* (No. 16).

Farooq, M. (2011). Factors affecting academic performance of students: A case of secondary School level. *Journal of Quality and Technology Management, 01-14,*

Fernández-Sánchez, A., Redondo-Tébar, A., Sánchez-López, M., Visier-Alfonso, M. E., Muñoz-Rodríguez, J. R., & Martínez-Vizcaíno, V. (2022). Sex differences on the relation among gross motor competence, cognition, and academic achievement in children. *Scandinavian Journal of Psychology, 63*(5), 504–512. 10.1111/sjop.12827

Figueroa, I. J., & Youmans, R. J. (2013). Failure to Maintain Set. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 57*(1), 828–832. 10.1177/1541931213571180

Fox, C. K., Barr-Anderson, D., Neumark-Sztainer, D., & Wall, M. (2010). Physical Activity and Sports Team Participation: Associations With Academic Outcomes in Middle School and High School Students. *Journal of School Health, 80*(1), 31–37. 10.1111/j.1746-1561.2009.00454.x

Fuhs, M. W., Nesbitt, K. T., Farran, D. C., & Dong, N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology, 50*(6), 1698–1709. 10.1037/a0036633

Gallahue, D. L., Ozmun, J. C., & Goodway, J. D. (2012). *Understanding Motor Development: Infants, Children, Adolescents, Adults* (7th ed.). McGrawHill.

Gandotra, A., Csaba, S., Sattar, Y., Cserényi, V., Bizonics, R., Cserjesi, R., & Kotyuk, E. (2022). A Meta-analysis of the Relationship between Motor Skills and Executive Functions in Typically-developing Children. *Journal of Cognition and Development, 23*(1), 83–110. 10.1080/15248372.2021.1979554

Gathercole, S. E., Brown, L., & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of National Curriculum attainment levels. *Educational Child Psychology, 20*, 109–122.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*(1), 1–16. 10.1002/acp.934

Ghorbanzadeh, B., Orangi, B. M., & Sahin, T. (2025). The relationship between motor competence and executive function as influenced by age, sex, and family socio-economic status. *Frontiers in Psychology, olume 16 - 2025* https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2025.1544168

Gibbs, R. W. (2005). *Embodiment and Cognitive Science*. Cambridge University Press.

Gilmour, A. M., MacDonald, M. J., Cox, A., Fairclough, S. J., & Tyler, R. (2023). Investigating Ecological Momentary Assessed Physical Activity and Core Executive Functions in 18- to 24-Year-Old Undergraduate Students. *International Journal of Environmental Research and Public Health, 20*(20)10.3390/ijerph20206944

Grant, D. A., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology, 38*(4), 404–411. 10.1037/h0059831

Guillamón, A. R., Cantó, E. G., & García, H. M. (2021). Motor coordination and academic performance in primary school students. *Journal of Human Sport and Exercise, 16*(2), 247–260. 10.14198/jhse.2021.162.02

Henderson, S. E., Sugden, D. A., Barnett, A. L., & Smits-Engelsman, B. C. M. (2010). *Movement Assessment Battery for Children* (2nd ed.). Pearson.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1–55. 10.1080/10705519909540118

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44*(11), 2017–2036. 10.1016/j.neuropsychologia.2006.01.010

Hulteen, R. M., Morgan, P. J., Barnett, L. M., Stodden, D. F., & Lubans, D. R. (2018). Development of Foundational Movement Skills: A Conceptual Model for Physical

Activity Across the Lifespan. *Sports Medicine, 48*(7), 1533–1540. 10.1007/s40279-018-0892-6

Hulteen, R. M., Terlizzi, B., Abrams, T. C., Sacko, R. S., De Meester, A., Pesce, C., & Stodden, D. F. (2023). Reinvest to Assess: Advancing Approaches to Motor Competence Measurement Across the Lifespan. *Sports Medicine, 53*(1), 33–50. 10.1007/s40279-022-01750-8

Humes, G. E., Welsh, M. C., & Retzlaff, P. (1997). TOWERS OF HANOI AND LONDON: RELIABILITY AND VALIDITY OF Two ExECUTIVE FuNCTION TASKS.

Iivonen, S., Kaarina Sääkslahti, A., & Laukkanen, A. (2015). A review of studies using the Körperkoordinationstest für Kinder (KTK). *European Journal of Adapted Physical Activity, 8*(2), 18–36. 10.5507/euj.2015.006

Johnco, C., Wuthrich, V. M., & Rapee, R. M. (2014). Reliability and validity of two self-report measures of cognitive flexibility. *Psychological Assessment, 26*(4), 1381–1387. 10.1037/a0038009

Khan, N. A., & Hillman, C. H. (2014). The Relation of Childhood Physical Activity and Aerobic Fitness to Brain Function and Cognition: A Review. *Pediatric Exercise Science, 26*(2), 138–146. 10.1123/pes.2013-0125

Kiphard, E. J., & Schiling, F. (1974). *Korperkoordinationtest fur kinder KTK: Manual.* Beltz Test.

Kline, R. B. (2016). *Principles and Practices of Structural Equation Modelling* (4th ed.). The Guildford Press.

Kline, R. B. (2023). *Principles and Practices of Structural Equation Modelling* (5th ed.). The Guildford Press.

Kyriazos, T. A. (2018). Applied Psychometrics: Sample Size and Sample Power Considerations in Factor Analysis (EFA, CFA) and SEM in General. *Psychology, 09*(08), 2207–2230. 10.4236/psych.2018.98126

Larkin, D., & Cermack, S. A. (2002). Issues in identification and assessment of developmental coordination disorder. In S. A. CERMACK, & D. LARKIN (Eds.), *Developmental Coordination Disorder* (pp. 86–102). Singular Publishing Group.

Li, L., Zhang, J., Cao, M., Hu, W., Zhou, T., Huang, T., Chen, P., & Quan, M. (2020). The effects of chronic physical activity interventions on executive functions in children aged 3–7 years: A meta-analysis. *Journal of Science and Medicine in Sport, 23*(10), 949–954. 10.1016/j.jsams.2020.03.007

Lin, J., Wen, X., Cui, X., Xiang, Y., Xie, J., Chen, Y., Huang, R., & Mo, L. (2020). Common and specific neural correlates underlying insight and ordinary problem solving. *Brain Imaging and Behavior, 15*(3), 1374. 10.1007/s11682-020-00337-z

Löffler, C., Frischkorn, G. T., Hagemann, D., Sadus, K., & Schubert, A. (2024). The common factor of executive functions measures nothing but speed of information uptake. *Psychological Research, 88*(4), 1092–1114. 10.1007/s00426-023-01924-7

Lohman, T. G., Roche, A. M., & Martorell, R. (1991). *Anthropometric standardisation reference manual*. Human Kinetics Books.

Lopes, L., Santos, R., Pereira, B., & Lopes, V. P. (2013a). Associations between gross Motor Coordination and Academic Achievement in elementary school children. *Human Movement Science, 32*(1), 9–20. 10.1016/j.humov.2012.05.005

Lopes, L., Santos, R., Pereira, B., & Lopes, V. P. (2013b). Associations between gross Motor Coordination and Academic Achievement in elementary school children. *Human Movement Science, 32*(1), 9–20. 10.1016/j.humov.2012.05.005

Ludyga, S., Pühse, U., Gerber, M., & Herrmann, C. (2019). Core executive functions are selectively related to different facets of motor competence in preadolescent children. *European Journal of Sport Science, 19*(3), 375–383. 10.1080/17461391.2018.1529826

Malambo, C., Nová, A., Clark, C., & Musálek, M. (2022). Associations between Fundamental Movement Skills, Physical Fitness, Motor Competency, Physical Activity, and Executive Functions in Pre-School Age Children: A Systematic Review. *Children, 9*(7), 1059. 10.3390/children9071059

Mayes, S. D., Calhoun, S. L., Bixler, E. O., & Zimmerman, D. N. (2009). IQ and neuropsychological predictors of academic achievement. *Learning and Individual Differences, 19*(2), 238–241. 10.1016/j.lindif.2008.09.001

McClelland, M. M., & Cameron, C. E. (2019). Developing together: The role of executive function and motor skills in children's early academic lives. *Early Childhood Research Quarterly, 46*, 142–151. 10.1016/j.ecresq.2018.03.014

Miles, S., Howlett, C. A., Berryman, C., Nedeljkovic, M., Lorimer Moseley, &. G., & Phillipou, A.Considerations for using the Wisconsin Card Sorting Test to assess cognitive flexibility.10.3758/s13428-021-01551-3/Published

Ministry of Housing, Communities, and Local Government. (2019). *English indices of deprivation 2019.* https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

Mitani, K., Rathnayake, N., Rathnayake, U., Dang, T. L., & Hoshino, Y. (2022). Brain Activity Associated with the Planning Process during the Long-Time Learning of the Tower of Hanoi (ToH) Task: A Pilot Study. *Sensors, 22*(21)10.3390/s22218283

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex

"Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. 10.1006/cogp.1999.0734

Morley, D., Rudd, J., Issartel, J., Goodway, J., O'Connor, D., Foulkes, J., Babic, M., Kavanagh, J., & Miller, A. (2021). Rationale and study protocol for the Movement Oriented Games Based Assessment (MOGBA) cluster randomized controlled trial: A complex movement skill intervention for 8–12 year old children within 'Made to Play'. *PLoS ONE, 16*(6 June)10.1371/journal.pone.0253747

Morley, D., Till, K., Ogilvie, P., & Turner, G. (2015). Influences of gender and socioeconomic status on the motor proficiency of children in the UK. *Human Movement Science, 44*, 150. 10.1016/j.humov.2015.08.022

Noble, M., Wright, G., Smith, G., & Dibben, C. (2006). Measuring Multiple Deprivation at the Small-Area Level. *Environment and Planning A: Economy and Space, 38*(1), 169. 10.1068/a37168

Oberer, N., Gashaj, V., & Roebers, C. M. (2018). Executive functions, visual-motor coordination, physical fitness and academic achievement: Longitudinal relations in typically developing children. *Human Movement Science, 58*, 69–79. 10.1016/j.humov.2018.01.003

O'Callaghan, L., Foweather, L., Crotti, M., Oppici, L., Pesce, C., Boddy, L., Fitton Davies, K., & Rudd, J. (2024). Associations of physical activity dose and movement quality with executive functions in socioeconomically disadvantaged children aged 5–6 years. *Psychology of Sport and Exercise, 70*, 102546. 10.1016/j.psychsport.2023.102546

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity, 32*(1), 1–11. 10.1038/sj.ijo.0803774

Pesce, C. (2012a). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport and Exercise Psychology, 34*(6), 766–786.

Pesce, C. (2012b). Shifting the Focus From Quantitative to Qualitative Exercise Characteristics in Exercise and Cognition Research. *Journal of Sport and Exercise Psychology, 34*(6), 766–786. 10.1123/jsep.34.6.766

Piek, J. P., Dawson, L., Smith, L. M., & Gasson, N. (2008). The role of early fine and gross motor development on later motor and cognitive ability. *Human Movement Science, 27*(5), 668–681. 10.1016/j.humov.2007.11.002

Pizzolato, J. E., Brown, E. L., & Kanny, M. A. (2011). Purpose plus: supporting youth purpose, control, and academic achievement. *New Directions for Youth Development, 2011*(132), 75–88, 10. 10.1002/yd.429

Rasberry, C. N., Lee, S. M., Robin, L., Laris, B. A., Russell, L. A., Coyle, K. K., & Nihiser, A. J. (2011). The association between school-based physical activity, including physical education, and academic performance: A systematic review of the literature. *Preventive Medicine, 52*, S10–S20. 10.1016/j.ypmed.2011.01.027

Ré, A. H. N., Logan, S. W., Cattuzzo, M. T., Henrique, R. S., Tudela, M. C., & and Stodden, D. F. (2018). Comparison of motor competence levels on two assessments across childhood. *Journal of Sports Sciences, 36*(1), 1–6. 10.1080/02640414.2016.1276294

Richard Ridderinkhof, K., Wylie, S. A., M van den Wildenberg, W. P., Bashore Jr, T. R., van der Molen, M. W., & Richard Ridderinkhof KRRidderinkhof, K.The arrow of time: Advancing insights into action control from the arrow version of the Eriksen flanker task.10.3758/s13414-020-02167-z/Published

Richards, A. B., Barker, H. G., Williams, E., Swindell, N., Mackintosh, K. A., Tyler, R., Griffiths, L. J., Foweather, L., & Stratton, G. (2023). Motor Competence between Children with and without Additional Learning Needs: A Cross-Sectional Population-Level Study. *Children, 10*(9)10.3390/children10091537

Rigoli, D., Piek, J. P., Kane, R., & Oosterlaan, J. (2012). Motor coordination, working memory, and academic achievement in a normative adolescent sample: Testing a mediation model. *Archives of Clinical Neuropsychology, 27*(7), 766–780. 10.1093/arclin/acs061

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., Rodrigues, L. P., & D'Hondt, E. (2015). Motor Competence and its Effect on Positive Developmental Trajectories of Health. *Sports Medicine, 45*(9), 1273–1284. 10.1007/s40279-015-0351-6

Roebers, C. M., & Kauer, M. (2009). Motor and cognitive control in a normative sample of 7-year-olds. *Developmental Science, 12*(1), 175–181. 10.1111/j.1467-7687.2008.00755.x

Schafer, J. L. (1999). Multiple imputation: a primer. *Statistical Methods in Medical Research, 8*(1), 3–15. 10.1177/096228029900800102

Schmidt, M., Egger, F., Benzing, V., Jäger, K., Conzelmann, A., Roebers, C. M., & Pesce, C. (2017). Disentangling the relationship between children's motor ability, executive function and academic achievement. *Plos One, 12*(8), e0182845. 10.1371/journal.pone.0182845

Siddi, S., Preti, A., Lara, E., Brébion, G., Vila, R., Iglesias, M., Cuevas-Esteban, J., López-Carrilero, R., Butjosa, A., & Haro, J. M. (2020). Comparison of the touch-screen and traditional versions of the Corsi block-tapping test in patients with psychosis and healthy controls. *BMC Psychiatry, 20*(1)10.1186/s12888-020-02716-8

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59*(4), 745–759. 10.1080/17470210500162854

Standards and Testing Agency. (2023). *Key stage 2 scaled score tables*

Sterne, J. A. C., White, I. R., Carlin, J. B., Spratt, M., Royston, P., Kenward, M. G., Wood, A. M., & Carpenter, J. R. (2009). Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. *BMJ, 338*(jun29 1), b2393–b2393. 10.1136/bmj.b2393

Stillman, C. M., Cohen, J., Lehman, M. E., & Erickson, K. I. (2016). Mediators of physical activity on neurocognitive function: A review at multiple levels of analysis. *Frontiers in Human Neuroscience, 10*(DEC2016)10.3389/fnhum.2016.00626

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. *Quest, 60*(2), 290–306. 10.1080/00336297.2008.10483582

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods, 42*(4), 1096–1104. 10.3758/BRM.42.4.1096

Stoet, G. (2017). PsyToolkit: A Novel Web-Based Method for Running Online Questionnaires and Reaction-Time Experiments. *Teaching of Psychology, 44*(1), 24–31. 10.1177/0098628316677643

Tchanturia, K., Davies, H., Roberts, M., Harrison, A., Nakazato, M., Schmidt, U., Treasure, J., & Morris, R. (2012). Poor Cognitive Flexibility in Eating Disorders: Examining the

Evidence using the Wisconsin Card Sorting Task. *Plos One, 7*(1), e28331. https://doi.org/10.1371/journal.pone.0028331

Tomporowski, P. D., & Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition via a common process. *Psychological Bulletin, 145*(9), 929.

Tyler, R., Atkin, A. J., Dainty, J. R., Dumuid, D., & Fairclough, S. J. (2022). Cross-sectional associations between 24-hour activity behaviours and motor competence in youth: a compositional data analysis. *Journal of Activity, Sedentary and Sleep Behaviors, 1*(1)10.1186/s44167-022-00003-3

Tyler, R., Foweather, L., Mackintosh, K. A., & Stratton, G. (2018). A Dynamic Assessment of Children's Physical Competence: The Dragon Challenge. *Medicine and Science in Sports and Exercise, 50*(12), 2474–2487. 10.1249/MSS.0000000000001739

Tyler, R., Mackintosh, K. A., Foweather, L., Edwards, L. C., & Stratton, G. (2020). Youth motor competence promotion model: a quantitative investigation into modifiable factors. *Journal of Science and Medicine in Sport, 23*(10), 955–961. 10.1016/j.jsams.2020.04.008

Ulrich, D. A. (2000). *Test of gross motor development* (2nd ed.). Pro-Ed.

van der Fels, I. M. J., te Wierike, S. C. M., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport, 18*(6), 697–703. 10.1016/j.jsams.2014.09.007

van der Niet, A. G., Hartman, E., Smith, J., & Visscher, C. (2014). Modeling relationships between physical fitness, executive functioning, and academic achievement in primary school children. *Psychology of Sport and Exercise, 15*(4), 319–325. 10.1016/j.psychsport.2014.02.010

van der Veer, G., Cantell, M. H., Minnaert, A. E. M. G., & Houwen, S. (2024). *The relationship between motor performance and executive functioning in early childhood: A systematic review on motor demands embedded within executive function tasks*. Routledge. 10.1080/21622965.2022.2128675

Vanhala, A., Haapala, E. A., Sääkslahti, A., Hakkarainen, A., Widlund, A., & Aunio, P. (2023). Associations between physical activity, motor skills, executive functions and early numeracy in preschoolers. *European Journal of Sport Science, 23*(7), 1385–1393. 10.1080/17461391.2022.2092777

Vermunt, J. D., & Endedijk, M. D. (2011). Patterns in teacher learning in different phases of the professional career. *Learning and Individual Differences, 21*(3), 294–302. 10.1016/j.lindif.2010.11.019

Viviani, G., Visalli, A., Finos, L., Vallesi, A., & Ambrosini, E. (2024). A comparison between different variants of the spatial Stroop task: The influence of analytic flexibility on Stroop effect estimates and reliability. *Behavior Research Methods, 56*(2), 934–951. 10.3758/s13428-023-02091-8

Wassenberg, R., Feron, F. J. M., Kessels, A. G. H., Hendriksen, J. G. M., Kalff, A. C., Kroes, M., Hurks, P. P. M., Beeren, M., Jolles, J., & Vles, J. S. H. (2005). Relation Between Cognitive and Motor Performance in 5- to 6-Year-Old Children: Results From a Large-Scale Cross-Sectional Study. *Child Development, 76*(5), 1092–1103. 10.1111/j.1467-8624.2005.00899.x

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology, 102*(1), 43–53. 10.1037/a0016738

Wiebe, S. A., Andrews Espy, K., Charak, D., & Wiebe, A. (2008). Supplemental Material for Using Confirmatory Factor Analysis to Understand Executive Control in Preschool Children: I. Latent Structure. *Developmental Psychology,* 10.1037/0012-1649.44.2.575.supp

Wilson, P. H., Ruddock, S., Smits-Engelsman, B., Polatajko, H., & Blank, R. (2013). *Understanding performance deficits in developmental coordination disorder: A meta-analysis of recent research*. Blackwell Publishing Ltd. 10.1111/j.1469-8749.2012.04436.x

Yeniad, N., Malda, M., Mesman, J., van IJzendoorn, M. H., & Pieper, S. (2013). Shifting ability predicts math and reading performance in children: A meta-analytical study. *Learning and Individual Differences, 23*, 1–9. 10.1016/j.lindif.2012.10.004

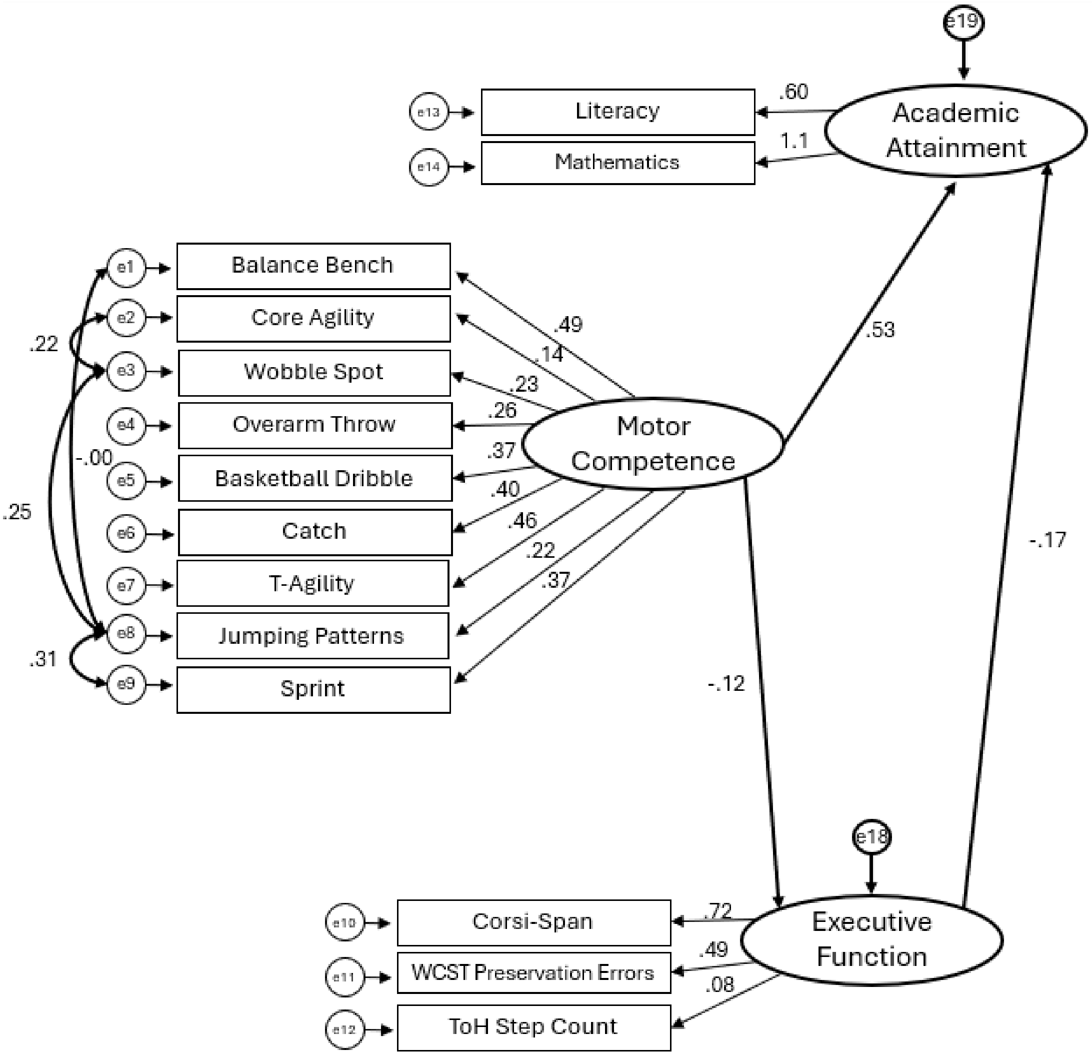
Zeegers, P. (2001). Approaches to learning in science: A longitudinal study. *British Journal of Educational Psychology, 71*(1), 115–132. 10.1348/000709901158424

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-allen, K., Beaumont, J. L., & Weintraub, S. (2013). II. NIH TOOLBOX COGNITION BATTERY (CB): MEASURING EXECUTIVE FUNCTION AND ATTENTION. *Monographs of the Society for Research in Child Development, 78*(4), 16. 10.1111/mono.12032

Supplementary Material 1

Figure 1

Final SEM evaluating relationships between motor competence, executive function, and academic attainment for those in low-medium deprivation areas.



Supplementary Material 2

Figure 2

Final SEM evaluating relationships between motor competence, executive function, and academic attainment for those in high-medium deprivation areas.