



Original research

Do our movement skills impact our cognitive skills? Exploring the relationship between cognitive function and fundamental movement skills in primary school children

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ABSTRACT

Objectives: The literature suggests that there is a relationship between motor function and cognitive development however, few studies have explored the specific role of Functional Movement Skills on cognitive function. This research aimed to determine if Functional Movement Skills predict cognitive function, when accounting for confounding factors, in a sample of primary school children in Ireland.

Design: Cross-sectional.

Methods: Sixty primary school children (51.7 % girls, age range 7–12 years, mean age 9.9 ± 1.28) were assessed in their Functional Movement Skill proficiency using the Test of Gross Motor Development—3rd Edition and a sub-test of the Bruininks–Oseretsky Test of Motor Proficiency 2 Short Form (to assess balance). Participants also completed a series of cognitive tests which formed part of the Cambridge Neuropsychological Test Automated Battery.

Results: A series of hierarchical regression analyses were conducted whilst controlling for covariates (Age; Gender; Socio Economic Status). Attention Switching, Reaction Time, and Emotional Recognition were found to be associated with Overall Functional Movement Skills (Locomotor, Object Control, Stability). Overall Functional Movement Skills significantly accounted for 4.7 % of the variance in Simple Reaction Time ($\Delta R^2 = 0.032$; $p = 0.13$) whilst Stability significantly accounted for 5.5 % ($\Delta R^2 = 0.055$; $p = 0.04$) and 12.9 % ($\Delta R^2 = 0.129$; $p = 0.00$) of the variance in Simple Reaction Time and Emotional Recognition, respectively, after controlling for covariates.

Conclusions: Overall Functional Movement Skills may be more related to reaction time than attention and spatial working memory, whilst stability may be more associated with emotional recognition. Further research is warranted. Greater comprehension of the impact of Functional Movement Skills on cognitive function in children can contribute to the development of more effective and efficient physical activity programmes, which can in turn contribute to and promote holistic child development.

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Practical implications

- Attention Switching, Reaction Time, and Emotional Recognition are significantly associated with Overall FMSs and its associated skills.
- The results suggest that Overall FMSs may be more closely related to reaction time than attention and spatial working memory.
- Stability was found to significantly predict Emotional Recognition.
- The findings of this study suggest that there may be some predictive relationship between FMSs and some cognitive functions and as such warrant further investigation.

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1. Introduction

Fundamental movement skills (FMSs) are an essential component of a child's overall development¹ and act as building blocks for adequate participation in multiple physical activities for children, adolescents, and adults. Commonly developed in childhood, FMSs include locomotor (e.g., running and hopping), object control (e.g., catching and throwing), and stability (e.g., balancing and twisting) skills. These skills play a considerable role and are used in practically every aspect of daily life. As well as providing the foundation for an active lifestyle, there is a growing body of evidence suggesting that the development of motor skills is directly associated with other aspects of development in early and middle life such as social, emotional, and cognitive development.^{1,2}

According to the research, motor skills are linked with cognitive development and function.^{3,4} Cognitive functioning refers to an individual's ability to acquire, organise and use knowledge and is essential for everyday behaviour. It permits us to understand and relate to the world around us. Cognitive development of higher order cognitive skills (e.g., executive functions – response inhibition, planning, attention, working memory, cognitive flexibility) are key components that are important in the development of a child, through adolescence and into adulthood.⁵ These components give children the ability to pay attention, retain and manipulate information appropriately, process information and respond quickly and accurately and alternate between task conditions.⁶ These cognitive skills are purported to be associated with motor skills^{3,4} with better motor skills found to be related to more efficient cognitive functions such as inhibitory control and working memory.⁷ The notion is supported by the idea that sensory and motor functioning regions of the brain are typically first to mature.³ Moreover, both motor and cognitive skills have several mutual fundamental processes such as sequencing, monitoring, and planning and are purported to have similar developmental timetables which are accelerated during childhood.⁴ According to Piaget's 'Cognitive Development Theory', motor development and cognitive development are related through "thinking by bodily movement" in which cognitive processes are enhanced by action created by the body. Roebers & Kauer⁴ examined over one hundred 7-year-olds with several cognitive executive tasks and motor coordination tasks. Performance in both types of tasks was found to be significantly interrelated, even when controlling for age. Moreover, neuroimaging studies have highlighted that regions of the brain formerly thought to be exclusively associated with motor activity (i.e., cerebellum and basal ganglia) or with cognition (i.e., prefrontal cortex) are in fact co-activated during the execution of specific cognitive or motor activities,¹⁸ thus further supporting the notion of a close relationship between motor and cognitive functions.

Bushnell and Boudreau⁹ proposed that motor development may act as a 'control parameter' for further development, such that some motor functions may act as a criterion for the successful acquisition of other developmental functions (i.e., perceptual and cognitive abilities). In their longitudinal study, Piek and colleagues² found that among a sample of Australian children aged 4 months–12 years, gross motor skills served as a significant predictor for subsequent cognitive performance (i.e., working memory and processing speed), after controlling for socio-economic status. When using the Bruininks–Oseretsky Test of Motor Proficiency (BOT-2), Niekerk et al.¹⁰ found that the motor competency (fine and gross motor abilities) of 13- to 14-year-olds in South Africa was significantly related to academic performance (i.e., English and Mathematics). Moreover, Lopes et al.¹¹ found that among Portuguese children aged 9–11 years, those with low gross motor coordination had a higher probability of having low academic achievement, after adjusting for cardiorespiratory fitness, body mass index, and socio-economic status.

The literature suggests that there is a relationship between motor function and cognitive development however, few studies have explored the specific impact of FMSs on cognitive function.¹ According to Carson et al.,¹² in childhood, one should begin to acquire and develop the ability to regulate one's attention, working memory, flexibility, and executive function. Therefore, the purpose of this research was to determine if FMS ability predicts cognitive function, specifically attention, reaction time, spatial working memory, and emotional recognition, when controlling for age, gender, and other confounding factors, in a sample of primary school children in Ireland. A greater understanding of the nature of this relationship may provide insights to teachers and movement specialists during the fundamental movement development phase in children.

2. Methods

The participants involved in this study were part of a wider physical literacy study known as "Moving Well-Being Well" (n = 2098, 47 %

girls, age range 5–12 years). There were 44 schools involved across 12 counties (56 % rural, 44 % urban) in Ireland and Northern Ireland. Areas classed as "socioeconomically disadvantaged" qualify for the Delivering Equality of Opportunity in Schools (DEIS) programme in Irish primary schools, and this study's sample includes 25.0 % DEIS schools (n = 15 DEIS schools, n = 45 non-DEIS schools). A subsample of schools and participants that captured demographics was selected, with 13 schools ranging across the primary school spectrum chosen which included 60 participants (n = 29 boys, n = 31 girls, age range 7–12 years, mean age 9.9 ± 1.28). The subsample of schools was selected in an effort to best represent the primary school landscape in Ireland, with an appropriate mix of urban, rural, DEIS and non DEIS schools participating. Ethical approval from the institution's Research Ethics Committee was obtained (DCU/REC/2017/029). Parental consent and participant assent were obtained. A unique numerical code was assigned to all participants to ensure that their anonymity was maintained. Data collection was conducted March through June 2017 across typically developing junior infants to sixth class children.

Participants' proficiency in FMSs was assessed using the Test of Gross Motor Development–3rd Edition (TGMD-3). The TGMD-3 comprises of a locomotor (run, skip, gallop, slide, hop, and horizontal jump) and an object-control assessment (catch, overhand throw, underhand roll, kick, two-handed strike, one-handed strike, and stationary dribble).¹³ A vertical jump test was also included, due to its context in Irish sport participation.¹⁴ Previous research has used these measurement tools repeatedly and both have a high degree of validity and reliability.¹⁵ These are performance based assessments, with both the TGMD-3 and the vertical jump test assessing the performance of skill components, rather than the outcome or product of the performance. Again, both have established validity and reliability ($\alpha = 0.81$) in this age cohort.¹⁵

As mentioned, the TGMD is a common assessment tool and has been employed in numerous studies, but a common criticism would highlight the lack of a stability component. In order to assess FMSs in the most complete way possible, a subtest of the Bruininks–Oseretsky Test of Motor Proficiency 2 (BOT-2) Short Form was used to assess the participants' balance. The BOT-2 Short Form is a motor competence battery originally designed to identify individuals with mild to severe motor problems. It has proven validity and reliability ($\alpha = 0.92$), and has been widely used in past research.¹⁵ The test consists of two tasks, walking forward along a straight line, and standing on one leg on a balance beam with eyes open. These assessments are scored on the outcome of the performance, in contrast to the TGMD-3, and participants score between 0 and 4 for each task.

The Cambridge Neuropsychological Test Automated Battery is a battery of computerised neuropsychological tests by the University of Cambridge, England¹⁶ which was used to assess participants' cognitive function. The CANTAB tests depend on touch screen technology, which provides rapid and non-invasive cognitive assessment and have been previously employed in other studies evaluating the cognitive functions of children from 4 to 12.¹⁷ Five tests from CANTAB were used to assess the cognitive functions of the participants, namely: i) attention switching (AST); ii) reaction time (RTI); iii) rapid visual information processing (RVP); iv) spatial working memory (SWM); and v) emotion recognition (ERT). Please see Table 1 for a breakdown of the cognitive constructs and their acronyms. A detailed technical description of the tests can be found on the Cambridge Cognition's website: <http://www.cantab.com>.

Each member of the research team underwent formal training in order to ensure familiarity and consistency with the assessments. In order to ensure consistency in the FMS measurement, all were required to meet a 95 % inter-observer agreement on a pre-coded data set, whilst being blind to the conditions of coding. A visual demonstration of the skill was performed prior to the assessment, by a trained member of the research team. This is consistent with the protocols identified by Ulrich,¹³ and mirrors the methods widely used throughout the

Table 1
Breakdown of cognitive constructs.

Cognitive construct	Acronym	Explanation
Attention switching Reaction time	ASTLCMD	Median Latency of Response (from stimulus appearance to button press) on Congruent Trials
	ASTLSWMD	Median Latency of Response (from stimulus appearance to button press) in Assessed Block(s) in Which the Rule is Switching
	RTIFMDRT	Reaction Time Median Five-Choice Reaction Time – The median duration it took for a participant to release the response button after the presentation of a target stimulus. Calculated across correct, assessed trials in which the stimulus could appear in any one of five locations
Sustained attention	RTISMDRT	Reaction Time Median Simple-Choice Reaction Time – The median duration it took for a participant to release the response button after the presentation of a target stimulus. Calculated across correct, assessed trials in which the stimulus could appear in one location only
	RVPA	Rapid Visual Information Processing Accuracy – RVP A prime: is the signal detection measure of a participant's sensitivity to the target sequence (string of three numbers), regardless of response tendency (the expected range is 0.00 to 1.00; bad to good). In essence, this metric is a measure of how good the participant is at detecting target sequences
Spatial working memory	RVPMDL	Rapid Visual Information Processing Median Response Latency – The median response latency on trials where the participant responded correctly. Calculated across all assessed trials
	SWMBE	Spatial Working Memory Between Errors – The number of times the participant incorrectly revisits a box in which a token has previously been found
Emotional recognition	SWMS	Spatial Working Memory Strategy; Emotional Recognition – The number of times a participant begins a new search pattern from the same box they started with previously. If they always begin a search from the same starting point we infer that the participant is employing a planned strategy for finding the tokens. Therefore, a low score indicates high strategy use (1 = they always begin the search from the same box), a high score indicates that they are beginning their searches from many different boxes.
	ERTOMDRT	Emotional Recognition Task Overall Median Reaction Time – The overall median latency for a participant to select an emotion word after being presented with a stimulus
	ERTTH	Emotional Recognition Task Total Hits – The total number of correct responses (emotion selection) the participant made across all assessed trials.

literature.^{13,15} No verbal feedback or cues were given, whilst participants were unaware of the components being assessed. Each participant first completed a practice trial to familiarise themselves, before being asked to perform every skill twice. The number of skill criteria varies from three to six across the various tests, with a score of one noted if the participant fulfilled the necessary criteria. A zero indicates that they failed to meet these criteria. The participants' raw score per skill was calculated from totalling scores from both trials. Upon completion of all skill assessments, the locomotor, object control, and balance skills were combined to give a raw Overall FMS score.

The first balance subtest, walking forward on a straight line, is graded based on the amount of steps a participant takes whilst adhering to strict criteria of the Bruininks–Oseretsky Test of Motor Proficiency. Points were awarded to the participant in line with the number of steps taken, e.g. six continuous steps equal four points. Standing on one leg on the balance beam was scored based on the time a child could maintain their balance whilst adhering to the prescribed criteria. Again, points were awarded based on the time a participant kept their balance, e.g. over 10 s equals four points. If a participant scored maximum points in the first trial, there was no need to complete a second trial.

FMS assessments are traditionally measured using the pen and paper method.¹³ A similar pen and paper method has been used in the past for the balance test. Before any statistical analyses can be undertaken, all results must be input into a database. This time-consuming method doubles the opportunity for human error during data entry. To alleviate this problem, a unique iPad application was developed to collect the data. The equivalent of the paper version was created in the iPad application. Further details are outlined in previous studies.¹⁸

The cognitive tests were administered and supervised by the lead psychologist and one other member of the research team, with a maximum of 8 participants per session. The tests were administered on iPad Air 2 (model: A1566, dimensions: 9.7 inch retina display) and were completed within 30 min. All participants received a detailed explanation on how to undertake each cognitive test and the tests were all carried out in the same sequence for each of the participant.

All data were analysed using SPSS version 24. A series of hierarchical regression analyses were conducted to determine whether the Overall FMSs (Total Overall FMS Score including Balance) along with its associated scores (Locomotor Skills (Raw Locomotor Score with Vertical Jump), Object Control Skills (Raw Object Control Score with One-Handed Strike), and Stability) accounted for incremental variance in cognitive functioning specifically attention switching, reaction time,

rapid visual information processing, spatial working memory, and emotion recognition, after controlling for covariates (Age; Gender; Socio Economic Status (SES)). In this hierarchical regression analysis, ΔR^2 represented the increase in the proportion of variance in the criterion variable explained from step $N - 1$ to step N . The sample size of 60 was sufficient to detect moderate to large relationships (i.e., $f^2 = 0.23$) between the criterion variables and the primary predictors.¹⁹

3. Results

Table 2 shows the means, standard deviations, and ranges for the study variables.

The correlations between the criterion variables, predictors, and control variables are shown in Table 3.

Table 2
Means, SDs, and range of scores for the study variables.

	Mean	SD	Range
Locomotor Skills ^a	47.75	6.92	29–58
Object Control Skills ^a	38.60	7.89	9–52
Stability ^a	6.68	1.69	2–8
Overall FMSs ^a	93.03	11.78	65–116
Attention Switching – ASTLCMD ^a	731.62	114.89	502.0–1004.0
Attention Switching – ASTLSWMD ^a	879.62	161.24	595.0–1310.5
Reaction Time – RTIFMDRT ^a	382.45	49.20	267.0–510.0
Reaction Time – RTISMDRT ^a	426.74	52.33	331.0–528.0
Sustained Attention – RVPA ^a	0.93	0.05	0.75–0.99
Sustained Attention – RVPMDL ^a	391.78	99.17	171.5–668.0
Spatial Working Memory – SWMBE ^a	19.40	7.58	1.0–35.0
Spatial Working Memory – SWMS ^a	8.93	1.62	3.0–12.0
Emotional Recognition – ERTOMDRT ^a	1385.75	366.32	811.5–2398.5
Emotional Recognition – ERTTH ^{a,b}	41.28	10.67	20.0–61.0
Age ^a	9.94	1.28	7.4–12.3

^a Raw score.

^b Total number of correct responses. Overall FMSs, Overall Functional Movement Skills; Attention Switching – ASTLCMD, Median Latency of Response on Congruent Trials; Attention Switching – ASTLSWMD, Median Latency of Response in Assessed Block(s) in Which the Rule is Switching; Reaction Time – RTIFMDRT, Reaction Time Median Five-Choice Reaction Time; Reaction Time – RTISMDRT, Reaction Time Median Simple-Choice Reaction Time; Sustained Attention – RVPA, Rapid Visual Information Processing Accuracy; Sustained Attention – RVPMDL, Rapid Visual Information Processing Median Response Latency; Spatial Working Memory – SWMBE, Spatial Working Memory Between Errors; Spatial Working Memory – SWMS, Spatial Working Memory Strategy; Emotional Recognition – ERTOMDRT, Emotional Recognition Task Overall Median Reaction Time; Emotional Recognition – ERTTH, Emotional Recognition Task Total Hits.

Table 3
Zero-order correlation matrix for the key and control variables.

	Locomotor Skills	Object Control Skills	Stability	Overall FMSs	Age	Gender	SES
Locomotor Skills							
Object Control Skills	0.168						
Stability	0.203	0.102					
Overall FMSs	0.729**	0.783**	0.331**				
Age	0.145	0.458**	0.282*	0.433**			
Gender	0.169τ	-0.346τ*	0.299τ*	-0.061τ	-0.065τ		
SES	0.095τ	0.237τ	0.155τ	0.160τ	0.190τ	0.019τ	
Attention Switching – ASTLCMD	-0.181	-0.336**	-0.299*	-0.374**	-0.507**	0.032τ	-0.234τ
Attention Switching – ASTLSWMD	-0.187	-0.256**	-0.148	-0.302*	-0.387**	0.032τ	-0.118τ
Reaction Time – RTISMDRT	-0.232	-0.354**	-0.354**	-0.424**	-0.519**	0.078τ	-0.139τ
Reaction Time – RTIFMDRT	-0.159	-0.421**	-0.320*	-0.422**	-0.581**	0.095τ	-0.352τ**
Sustained Attention – RVPA	0.054	0.030	0.242	0.086	0.485**	0.065τ	-0.020τ
Sustained Attention – RVPMDL	-0.176	-0.147	-0.216	-0.232	-0.392**	0.086τ	-0.157τ
Spatial Working Memory – SWMBE	-0.061	-0.083	-0.246	-0.127	-0.471**	-0.123τ	-0.024τ
Spatial Working Memory – SWMS	-0.205	-0.124	-0.137	-0.223	-0.262*	-0.038τ	-0.055τ
Emotional Recognition – ERTOMDRT	0.200	-0.059	-0.244	0.043	-0.264*	0.067τ	-0.040τ
Emotional Recognition – ERTTH	-0.043	0.156	0.441**	0.142	-0.398**	0.091τ	-0.107τ

τ = non-parametric test (Spearman's Rank).

Overall FMSs, Overall Functional Movement Skills; SES, Socio-Economic Status of School (DEIS, Non-DEIS); Attention Switching – ASTLCMD, Median Latency of Response on Congruent Trials; Attention Switching – ASTLSWMD, Median Latency of Response in Assessed Block(s) in Which the Rule is Switching; Reaction Time – RTIFMDRT, Reaction Time Median Five-Choice Reaction Time; Reaction Time – RTISMDRT, Reaction Time Median Simple-Choice Reaction Time; Sustained Attention – RVPA, Rapid Visual Information Processing Accuracy; Sustained Attention – RVPMDL, Rapid Visual Information Processing Median Response Latency; Spatial Working Memory – SWMBE, Spatial Working Memory Between Errors; Spatial Working Memory – SWMS, Spatial Working Memory Strategy; Emotional Recognition – ERTOMDRT, Emotional Recognition Task Overall Median Reaction Time; Emotional Recognition – ERTTH, Emotional Recognition Task Total Hits.

** p < 0.01 (two-tailed).

* p < 0.05 (two-tailed).

As expected, there were strong correlations between Overall FMSs and Locomotor Skills, Object Control Skills, and Stability, respectively (see Table 3). Overall FMSs and each of its associated scores were included in each of the models. Only those proposed covariates (i.e., age; gender; SES) that were significantly associated with Locomotor Skills, Object Control Skills, Stability, and/or Overall FMSs were included in the hierarchical regression analyses. Age was entered first (SES was also included for the RTIFMDRT variable) (Table 3 indicates that these were the only covariates) followed by Overall FMSs, Locomotor Skills, Object Control Skills, or Stability, respectively.

Attention switching. After controlling for age, Overall FMSs explained no additional variance in ASTLCMD ($\Delta R^2 = 0.032$; $p = 0.13$). Similarly, Locomotor Skills, Object Control Skills, or Stability was not found to explain any additional variance over and above that already explained by

age in ASTLCMD, $\Delta R^2 = 0.016$; $p = 0.34$, $\Delta R^2 = 0.014$; $p = 0.30$ and $\Delta R^2 = 0.033$; $p = 0.15$, respectively.

After controlling for age, Overall FMSs explained no additional variance in ASTLSWMD ($\Delta R^2 = 0.021$; $p = 0.21$). Similarly, Locomotor Skills, Object Control Skills, or Stability was not found to explain any additional variance over and above that already explained by age in ASTLSWMD, $\Delta R^2 = 0.020$; $p = 0.28$, $\Delta R^2 = 0.007$; $p = 0.46$ and $\Delta R^2 = 0.002$; $p = 0.74$, respectively. Table 4 summarises the regression results for the attention switching task.

Reaction time. After controlling for age, Overall FMS score explained a significant 5.5 % of the variance in reaction time in the median simple-choice reaction time task (RTISMDMT) ($\Delta R^2 = 0.055$; $p = 0.04$). Locomotor Skills and Object Control Skills were not found to explain any additional variance over and above that already explained by age in RTISMDMT, $\Delta R^2 = 0.034$; $p = 0.16$ and $\Delta R^2 = 0.019$; $p = 0.24$,

Table 4
Statistics for hierarchical multiple regression analyses predicting reaction time from Overall FMSs, Locomotor Skills, Object Control Skills, and Stability scores (n = 60).

	Attention switching outcomes							
	ASTLCMD				ASTLSWMD			
	B	95 % CI	sr ²	p-Value	B	95 % CI	sr ²	p-Value
Model 1 predictors								
Age	3.00	0.50, 5.50	0.187	0.00**	3.41	1.06, 5.76	0.187	0.00**
Overall FMSs	-0.02	-0.04, -0.00	0.032	0.13	-0.01	-0.03, 0.00	0.021	0.21
Total R ²			0.219	0.00**			0.209	0.00**
Model 2 predictors								
Age	0.51	-7.14, 33.97	0.021	0.26	0.46	-1.05, 1.98	0.021	0.26
Locomotor Skills	-0.27	-1.47, -0.01	0.016	0.34	-0.00	-0.01, 0.00	0.028	0.28
Total R ²			0.037	0.34			0.041	0.30
Model 3 predictors								
Age	2.38	0.71, 4.05	0.210	0.00**	2.60	1.03, 4.16	0.210	0.00**
Object Control Skills	-0.01	-0.02, 0.00	0.014	0.30	-0.00	-0.01, 0.00	0.007	0.46
Total R ²			0.224	0.00**			0.217	0.00**
Model 4 predictors								
Age	0.23	-0.15, 0.61	0.079	0.02*	0.34	-0.01, 0.71	0.079	0.02*
Stability	-0.00	-0.00, 0.00	0.033	0.15	0.00	-0.00, 0.00	0.002	0.74
Total R ²			0.112	0.03*			0.081	0.09

B, unstandardized regression coefficient; CI, confidence interval; sr², the part correlation squared; Attention Switching – ASTLCMD, Median Latency of Response on Congruent Trials; Attention Switching – ASTLSWMD, Median Latency of Response in Assessed Block(s) in Which the Rule is Switching; Overall FMSs, Overall Functional Movement Skills.

** <0.01.

* <0.05.

Table 5
Statistics for hierarchical multiple regression analyses predicting reaction time from Overall FMSs, Locomotor Skills, Object Control Skills, and Stability scores (n = 60).

	Reaction time outcomes							
	RTISMDRT				RTIFMDRT			
	B	95 % CI	sr ²	p-Value	B	95 % CI	sr ²	p-Value
Model 1 predictors								
Age	2.67	0.18, 5.15	0.187	0.00**	2.61	-0.03, 5.26	0.187	0.00**
SES	-	-	-	-	1.03	-5.62, 7.70	0.008	0.44
Overall FMSs	-0.06	-0.13, -0.00	0.055	0.04*	-0.05	-0.12, 0.01	0.037	0.10
Total R ²			0.242	0.00**			0.232	0.00**
Model 2 predictors								
Age	0.18	-1.44, 1.81	0.021	0.26	0.41	-1.32, 2.15	0.021	0.26
SES	-	-	-	-	-1.65	-6.02, 2.72	0.005	0.59
Locomotor Skills	-0.03	-0.07, 0.01	0.034	0.16	-0.01	-0.06, 0.02	0.013	0.38
Total R ²			0.055	0.20			0.039	0.51
Model 3 predictors								
Age	2.31	0.63, 3.98	0.210	0.00**	2.00	0.26, 3.74	0.210	0.00**
SES	-	-	-	-	2.34	-2.03, 6.71	0.029	0.14
Object Control Skills	-0.02	-0.06, 0.01	0.019	0.24	-0.02	-0.07, 0.01	0.023	0.19
Total R ²			0.201	0.00**			0.262	0.00**
Model 4 predictors								
Age	0.17	-0.20, 0.55	0.079	0.02*	0.19	-0.21, 0.60	0.079	0.02*
SES	-	-	-	-	0.34	-0.67, 1.37	0.018	0.28
Stability	-0.01	-0.02, 0.00	0.059	0.05	-0.00	-0.01, 0.00	0.026	0.20
Total R ²			0.138	0.01**			0.124	0.05

B, unstandardized regression coefficient; CI, confidence interval; sr², the part correlation squared; Reaction Time – RTISMDRT, Reaction Time Median Simple-Choice Reaction Time; Reaction Time – RTIFMDRT, Reaction Time Median Five-Choice Reaction Time; Overall FMSs, Overall Functional Movement Skills; SES, Socio-Economic Status of School (DEIS, Non-DEIS).
** <0.01.
* <0.05.

respectively. Although not quite significant (p = 0.05), Stability was found to explain a significant 5.9 % of the variance in RTISMDMT ($\Delta R^2 = 0.059$; p = 0.05). Table 4 summarises the regression results for the reaction time task.

After controlling for the two covariates (SES was found to be correlated with reaction time in the median five-choice reaction time task (RTIFMDMT)), Overall FMSs explained no additional variance in RTIFMDMT ($\Delta R^2 = 0.037$; p = 0.10). Similarly, Locomotor Skills, Object Control Skills, or Stability was not found to explain any additional variance over and above that already explained by the covariates in RTIFMDMT, $\Delta R^2 = 0.012$; p = 0.40, $\Delta R^2 = 0.001$; p = 0.80, $\Delta R^2 = 0.026$; p = 0.20, respectively (Table 5).

Table 6
Statistics for hierarchical multiple regression analyses predicting emotional recognition from Overall FMSs, Locomotor Skills, Object Control Skills, and Stability scores (n = 60).

	Emotional recognition outcomes			
	ERTTH			
	B	95 % CI	sr ²	p-Value
Model 1 predictors				
Age	4.10	1.71, 6.50	0.187	0.00**
Overall FMSs	-0.03	-0.32, 0.24	0.001	0.78
Total R ²			0.188	0.00**
Model 2 predictors				
Age	1.04	-0.49, 2.57	0.021	0.26
Locomotor Skills	-0.07	-0.26, 0.10	0.012	0.40
Total R ²			0.033	0.38
Model 3 predictors				
Age	2.89	1.31, 4.48	0.210	0.00**
Object Control Skills	-0.02	-0.21, 0.16	0.001	0.80
Total R ²			0.211	0.00**
Model 4 predictors				
Age	0.16	-0.17, 0.50	0.079	0.02*
Stability	0.06	0.02, 0.10	0.129	0.00**
Total R ²			0.208	0.00**

B, unstandardized regression coefficient; CI, confidence interval; sr², the part correlation squared; Emotional Recognition – ERTTH, Emotional Recognition Task Total Hits; Overall FMSs, Overall Functional Movement Skills.
** <0.01.
* <0.05.

Emotional recognition. After controlling for age, Overall FMSs explained no additional variance in ERTTH ($\Delta R^2 = 0.037$; p = 0.10). Locomotor Skills and Object Control Skills were not found to explain any additional variance over and above that already explained by age in ERTTH, $\Delta R^2 = 0.012$; p = 0.40 and $\Delta R^2 = 0.001$; p = 0.80, respectively. However, Stability was found to explain a significant 12.9 % of the variance in ERTTH ($\Delta R^2 = 0.129$; p = 0.00). Table 6 summarises the regression results for the emotional recognition task.

4. Discussion

The present study aimed to determine if FMSs predicted cognitive function among a sample of primary school children in Ireland. It was found that Overall FMSs accounted for a significant proportion of the variance in simple reaction time (5.5 %) but not in attention, spatial working memory, emotional recognition, or choice reaction time when accounting for age, gender, and SES. Stability was also found to account for a significant proportion of the variance in emotional recognition (12.9 %). These results suggest that Overall FMSs may be more closely related to reaction time than attention and spatial working memory whilst stability may be particularly associated with emotional recognition.

Object Control Skills, Stability and Overall FMSs were all found to be significantly moderately negatively associated with both simple and choice reaction times. However, FMSs were found to predict simple reaction time but not choice reaction time. Reaction times, the intervals between exposure to an external stimulus and a response, are considered at the most basic level an indicator of the processing speed of the nervous system.²⁰ Reaction speeds involve a combination of consistently attending and efficiently engaging the motor system.²⁰ As such, it is reasonable to propose that those with better FMSs as well as better Stability skills would have faster response times due to their ability to sense shifts in body positions and rapidly adjust and maintain equilibrium within the body in response to compensating movements.²¹ In their longitudinal study on children aged 5–7 years with and without motor coordination impairments, Michel et al.²² found that children with poor motor coordination were not slower in a simple reaction time task. Moreover, it was found that performance on cognitive tasks

was not less accurate but overall slower compared to those without motor coordination impairments, with the authors purporting that those in the impairment group performed slower because of the complex task demands, including the necessity to react as fast and as accurate as possible.

In line with the existing literature, performance on the attention switching task was found in this study to be moderately positively associated with both Object Control Skills and Overall FMSs. In their study of 238 children aged between 6 and 15 years, Piek and colleagues²³ found a strong association between attention and motor control. Michel et al.²² also found that children with poorer motor coordination performed worse in an attention switching task (Cognitive Flexibility task). Furthermore, children with motor problems often have attentional issues and vice versa²⁴ thus suggesting a close interaction between the two variables. Whilst FMS was associated with attention switching, it was not found to predict performance on the attention switching task in the current study. However, the close association between attention and motor coordination potentially suggests that they may share some common underlying neurocognitive mechanism.²³ The neural circuits recruited by both motor coordination and executive attention comprise the prefrontal cortex (PFC)⁸ and are purported to be co-activated and significantly interrelated.^{4,8} According to Roebbers and Kauer,⁴ this interrelation may indicate common processes in complex cognitive and motor actions potentially suggesting that there are shared higher order cognitive processes involved in cognitive executive tasks and motor coordination tasks.

Stability is considered the most basic skills within the FMS family and is defined as the ability to sense a shift in the relationship of the body parts that alter one's balance.²¹ In the present study, Stability was found to explain a significant 12.9% of the variance in the emotional recognition task. Interestingly, King-Dowling and colleagues²⁵ found that children aged 3–6 years who were found to have poor motor coordination also tended to have more emotional and behavioural problems (e.g., increased aggression, withdrawn symptoms) compared with their typically developing peers. James and colleagues²⁶ conducted an exploratory study to assess the impact of the *Move 2 Smile* programme on FMSs and social-emotional learning with parents reporting considerable positive impacts of the programme on ability to recognise and also express emotions. Functional neuroimaging studies on humans found that motor skill learning was associated with activation of many brain areas in the frontoparietal cortices, an area of the brain particularly associated with recognition of emotions.²⁸ In another study among thirty 10–13-year-old boys, it was found that those with greater emotional intelligence were found to have greater motor proficiency.²⁷ Furthermore, Piek et al.²⁹ found that between the ages of 4 months and 4 years, gross motor skill development is significantly related to anxiety and depression scores and that failure to achieve specific motor milestones results in greater anxiety and depression in school-aged children.

The current study has some limitations. This research cannot determine the directional relationship between the motor and cognitive domains. There is some evidence to suggest that motor development may predict cognitive performance however, further longitudinal research is warranted. It is also important to note that in attempting to interpret the results from this study, other variables may have played an influencing role (e.g., processing speed, motivation) which could have impacted results.³ Whilst the current sample size was sufficient to detect some relationships, it is suggested that research could benefit from exploring these relationships with a greater sample size. However, whilst a larger sample size would be desirable, the time intense nature of the assessment for both the participant and assessor, as well as the assessment costs per user, must be considered.

5. Conclusion

The findings from this research suggest specific relationships between Overall FMSs and its associated skills, and cognitive function

specifically attention switching, reaction time, and emotional recognition. It is possible that the specific relationships found in the present study may be assumed through shared neural mechanisms, namely, cerebellar processes. Only simple reaction time and emotional recognition were found to significantly predict FMSs. The current results have practical implications when considering interventions for some FMSs and/or cognitive functioning. Further research on the collective relations between FMSs and a broad range of developmental outcomes (i.e., cognitive development; social–emotional development) is warranted. Greater comprehension of the impact of skills such as spatial working memory and emotional recognition on learning and cognition in children can contribute to the design and development of more effective and efficient physical exercise programmes which can contribute and promote not just physical and social development but also enhance children's cognition.

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Declaration of interest statement

None.

Confirmation of ethical compliance

Ethical approval from the institution's Research Ethics Committee was obtained (DCU/REC/2017/029). Parental consent and participant assent were obtained. A unique numerical code was assigned to all participants to ensure that their anonymity was maintained.

References

- Bremer E, Cairney J. Fundamental movement skills and health-related outcomes: a narrative review of longitudinal and intervention studies targeting typically developing children. *Am J Lifestyle Med* 2016;12(2):148–159.
- Piek JP, Dawson L, Smith LM et al. The role of early fine and gross motor development on later motor and cognitive ability. *Hum Mov Sci* 2008;27(5):668–681.
- Rigoli D, Piek JP, Kane R et al. An examination of the relationship between motor coordination and executive functions in adolescents. *Dev Med Child Neurol* 2012;54(11):1025–1031.
- Roebbers CM, Kauer M. Motor and cognitive control in a normative sample of 7-year-olds. *Dev Sci* 2009;12(1):175–181.
- Munakata Y, Snyder HR, Chatham CH. Developing cognitive control: three key transitions. *Curr Dir Psychol Sci* 2012;21(2):71–77.
- Davidson MC, Amso D, Anderson LC et al. Development of cognitive control and executive functions from 4 to 13 years: evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia* 2006;44(11):2037–2078.
- Haapala EA. Cardiorespiratory fitness and motor skills in relation to cognition and academic performance in children – a review. *J Hum Kinet* 2013;28(36):55–68.
- Diamond A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Dev* 2000;71(1):44–56.
- Bushnell EW, Boudreau JP. Motor development and the mind: the potential role of motor abilities as a determinant of aspects of perceptual development. *Child Dev* 1993;64(4):1005–1021.
- Niekerk LV, Toit DD, Pienaar AE. *The relationship between motor proficiency and academic performance of adolescent learners in Potchefstroom*, 16South Africa, The PAHL Study, 2015.
- Lopes L, Santos R, Pereira B et al. Associations between gross Motor Coordination and Academic Achievement in elementary school children. *Hum Mov Sci* 2013;32(1):9–20.
- Carson V, Hunter S, Kuzik N et al. Systematic review of physical activity and cognitive development in early childhood. *J Sci Med Sport* 2016;19(7):573–578.
- Ulrich DA. Introduction to the special section: evaluation of the psychometric properties of the TGMD-3. *J Mot Learn Dev* 2017;5(1):1–4.
- O'Brien W, Belton S, Issartel J. The relationship between adolescents' physical activity, fundamental movement skills and weight status. *J Sports Sci* 2016;34(12):1159–1167.
- Cools W, Martelaer KD, Vandaele B et al. General fundamental movement skill development of 4- to 6-year-old pre-school children in Flanders. *J Sports Sci* 2009;27(51):1–35.
- Smith PJ, Need AC, Cirulli ET et al. A comparison of the Cambridge Automated Neuropsychological Test Battery (CANTAB) with "traditional" neuropsychological testing instruments. *J Clin Exp Neuropsychol* 2013;35(3):319–328.

17. Robinson SM, Crozier SR, Miles EA et al. Preconception maternal iodine status is positively associated with IQ but not with measures of executive function in childhood. *J Nutr* 2018;148(6):959-966.
18. Behan S, Belton S, Peers C et al. Exploring the relationships between fundamental movement skills and health related fitness components in children. *Eur J Sport Sci* 2020;0(0):1-11.
19. Faul F, Erdfelder E, Buchner A et al. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 2009;41(4):1149-1160.
20. Klotz JM, Johnson MD, Wu SW et al. Relationship between reaction time variability and motor skill development in ADHD. *Child Neuropsychol J Norm Abnorm Dev Child Adolesc* 2012;18(6):576-585.
21. Gallahue DL, Ozmun JC, Goodway J. *Understanding Motor Development: Infants, Children, Adolescents, Adults*, New York, McGraw-Hill, 2012.
22. Michel E, Roethlisberger M, Neuenschwander R et al. Development of cognitive skills in children with motor coordination impairments at 12-month follow-up. *Child Neuropsychol* 2011;17(2):151-172.
23. Piek JP, Dyck MJ, Nieman A et al. The relationship between motor coordination, executive functioning and attention in school aged children. *Arch Clin Neuropsychol* 2004;19(8):1063-1076.
24. Pitcher TM, Piek JP, Hay DA. Fine and gross motor ability in males with ADHD. *Dev Med Child Neurol* 2003;45(8):525-535.
25. King-Dowling S, Missiuna C, Rodriguez MC et al. Co-occurring motor, language and emotional-behavioral problems in children 3-6 years of age. *Hum Mov Sci* 2015;39:101-108.
26. James ME, Bedard C, Bremer E et al. The acceptability and feasibility of a preschool intervention targeting motor, social, and emotional development. *Front Pediatr* 2020;8:319. doi:10.3389/fped.2020.00319. PMID: 32754559; PMCID: PMC7366389.
27. Mohammadi Orangi B, Ghadiri F, Aghdasi M et al. The effect of local indigenous games on motor proficiency in elemental boys in Tehran with high and low emotional intelligence. *Mot Behav [Internet]* 2021;13(43). Available from: https://mbj.ssrc.ac.ir/article_1657.html. [cited 2021 Aug 5].
28. Adolphs R. Neural systems for recognizing emotion. *Curr Opin Neurobiol* 2002;12(2):169-177.
29. Piek JP, Barrett NC, Smith LM et al. Do motor skills in infancy and early childhood predict anxious and depressive symptomatology at school age? *Hum Mov Sci* 2010;29(5):777-786.