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Research article

Motor and cognitive skills implicated in the Motor Observation Questionnaire for Teachers (MOQ-T): A multidisciplinary approach

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ABSTRACT

This study was designed to determine the relationship between an observational measure of motor skills for teachers (i.e., MOQ-T), age, and some objectively assessed cognitive and motor indices. Two further goals were to examine which motor and cognitive factors predicted MOQ-T scores and to explore whether pupils with very low motor skills identified through MOQ-T also exhibited lower scores on objectively assessed motor and visuo-spatial tasks. A sample of 156 pupils aged 8.4 years–11.3 years and attending Italian primary school completed a battery of tests assessing writing speed, visuo-spatial abstract reasoning, fluency, and static balance abilities objectively assessed by measuring postural sway. Small to medium associations were found between MOQ-T scores and age, motor, and cognitive parameters, respectively. Moreover, approximately 26% of the variance in MOQ-T was predicted by sway area in the eyes-open condition, visuo-spatial fluency, and writing speed. Finally, pupils at risk of developmental coordination disorder exhibited poorer writing speed, and motor and higher-order visuo-spatial deficits. In conclusion, the synergistic use of objective measures of motor and cognitive functioning and observational screening questionnaires such as MOQ-T should be encouraged at school to identify pupils at risk of developmental coordination disorder.

1. Introduction

It is widely acknowledged in the literature that the development of motor and visuo-spatial skills play a crucial role in learning the properties of the surrounding world from early infancy (for a review, see Ref. [1]). Indeed, as Piaget [2] claimed, since the sensori-motor stage, infants after the age of 1 month use circular reactions are the medium to perform motor patterns necessary to discover the environment and build sensory-motor intelligence, which, in turn, drives their successive cognitive and motor development. Concerning this, Libertus and Violi [3] demonstrated that children between the ages of 3 and 5 months who exhibited very good postural patterns, between the ages of 10 and 14 months displayed a larger receptive vocabulary. In addition, when children acquire locomotion skills (i.e., around the age of 12–18 months), they can use their hands not only to manipulate objects but also for referential gestural communication (e.g., pointing to one toy), for example, to attract the attention of caregivers [4].

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A significant milestone of motor development is the ability to achieve the desired body position and maintain it in both static and dynamic situations in the presence of external perturbations (above all, gravity), that is, having good postural control. Although children can stand independently at around 1 year, the postural control system is subject to further maturation until early adolescence. In this regard, several studies have suggested that its non-optimal development may negatively affect motor development as a whole; the early identification of deficits in balance is therefore of great importance [5].

Moreover, Diamond [6] argued that in childhood motor and visuo-spatial skills develop interdependently and similarly in trends (i. e., they accelerate between the ages of 5 and 10 years, and continue to develop through adolescence as children learn to use motor imagery to perform complex mental operations), since they share some neural correlates (e.g., the prefrontal cortex, and cerebellum). Thus, it is well established that in the early stages of lifespan (i.e., between 4 and 16 years of age), the development of fine motor skills (i.e., a set of competencies involving the coordination of small muscles to control small, precise hands movements) and body coordination are associated with the development of visuo-spatial fluid intelligence, visual processing, and non-verbal working memory [7].

Assuming an atypical development perspective, the onset of a neurodevelopmental disorder called Developmental Coordination Disorder (DCD) occurs in the early stages but is usually diagnosed after the age of 5. DCD is characterized by a significant delay in the development of fine and gross (i.e., requiring the control of large muscles to move the body and have balance) motor skills, and visuo-motor coordination, whereas perceptual visual deficits, motor-related neurological conditions (e.g., muscular dystrophy and cerebral palsy), or intellectual deficits lack [8]. Specifically, children diagnosed with DCD are clumsy (e.g., bumping into objects), inaccurate, and/or slow in performing motor tasks (e.g., handwriting), and this can interfere with daily activities at home and school. Motor milestones such as crawling, sitting, and walking may be delayed, while the transition time from crawling to independent walking may be a lengthy one [9]. In addition, even when motor development is achieved, individuals exhibiting this neurodevelopmental condition are slow, imprecise, and clumsy in performing daily routines requiring motor coordination (e.g., buttoning a shirt, cutting a piece of meat with cutlery, and using scissors [8]). Moreover, among the wide spectrum of motor control issues, compared with their typically developing (TD) peers, children with DCD often exhibit poorer balance, whether this is instrumentally assessed using force/pressure platforms (i.e., calculating postural sway parameters) or using the balance subscales of the Movement Assessment Battery for Children [10]. In particular, the degree of balance impairments has been found associated with task difficulties and access to sensory information [11].

From a cognitive viewpoint, compared with TD children, pupils with DCD exhibit impaired visuo-constructive [12], passive (i.e., implicated in the temporary maintenance), and active (i.e., engaged in the information processing) verbal and visuo-spatial working memory [12,13], sustained attention, inhibition [13,14], motor planning [13,15], verbal and visuo-spatial fluency, and non-verbal set-shifting processes [13]. Therefore, as reported in the literature, the academic achievement of children with DCD is consequently poorer, since they may have slower handwriting [16], and problems with mathematics (e.g., poorer number facts retrieval, and mental and procedural calculation skills; [17], reading, and spelling difficulties [18]. Moreover, according to Poletti [19], there must be at least a partial overlapping between DCD and visuo-spatial learning deficits, since performance in academic subjects requiring visuo-spatial processing (e.g., geography, the natural sciences, and geometry) can be impaired. Finally, DCD is often associated with a higher risk of obesity (partly because children with this neurodevelopmental condition are less engaged in sports and general aerobic physical activities), reduced day-to-day autonomy, less social engagement, and a lower quality of life [e.g. Ref. [20]].

DCD is found in 2–6% of children [8]. It affects approximately 1.09% of those attending primary school [21], and in 30–70% of cases persists into adulthood [22], causing poor performance at work (because such individuals are slow and have difficulty learning complex motor routines). However, the prevalence of this neurodevelopmental condition is underestimated [23], and it is not always recognised. According to Asunta et al. [24], the little attention paid to DCD perhaps is due to the fact that professionals such as teachers and psychologists are dimly aware of it. Also, the inter-individual variability of the disorder's expression and its possible comorbidity with further neurodevelopmental conditions such as ADHD or specific learning impairments [20,25] make it more difficult to diagnose. Therefore, as recommended by Asunta et al. [26], it is urgent promoting the use of valid and reliable screening instruments in schools to identify children with DCD. In this regard, an internationally validated observational tool is the Motor Observation Questionnaire for Teachers (MOQ-T [27], which in its Italian version [28] was used to conduct the current study (see the Materials section). The questionnaire measures the frequency of problems relating to global motor function and handwriting/fine motor skills (whether at school or home), as reported by teachers [24,27,29]. However, unlike the original version, in the Polish validation, the authors detected three factors assessing gross motor skills, fine motor skills, and motor coordination in pupils attending primary school [30]. Overall, there is evidence that the MOQ-T is a reliable tool that correlates with objective measures of gross motor skills [30], fine motor skills, and manual dexterity [24,27,31], ideomotor and praxic skills [29]. Furthermore, children exhibiting symptoms of DCD evaluated through MOQ-T also exhibited poorer passive and active sequential visuo-spatial working memory [29].

However, even though MOQ-T focuses on the evaluation of motor difficulties in children's daily lives, to date, studies that examine the nature of the relationship between the MOQ-T scores and objectively assessed parameters indicative of the effectiveness of the postural control system (which, in turn, underpins aerobic exercise interventions promoted at school) are lacking. Similarly, while the MOQ-T encompasses several items assessing writing skills, as pointed out by Giofrè et al. [28], no studies have examined the associations between the evaluations of teachers through the questionnaire and the writing efficiency of children assessed through objective tests. Moreover, aside from the studies that validated the Italian version of the MOQ-T [28,29], to the best of our knowledge, no further investigations have been conducted in the Italian context into its usefulness in identifying children at risk of DCD. In our opinion, this is somewhat surprising, because as argued by Giofrè et al. [28], in the Italian context teachers have limited access to standardised tools that can detect the symptoms of DCD. As a result, diagnoses may be delayed and, as was noted above, the prevalence of the condition may be underestimated [28]. Therefore, the present study aimed to reach the following goals: 1) can the nature of the relationships between teachers' evaluation of motor skills as expressed through MOQ-T (see the Materials section), the objective scores of speed writing, motor, and visuo-spatial higher-order abilities, and age amongst a sample of school-aged children be examined? 2) can we investigate which motor and cognitive measures predicted MOQ-T scores? 3) can we explore whether pupils who were considered to have very poor motor skills (i.e., as identified through MOQ-T) also exhibited poor postural control and visuo-spatial skills? Following the literature, we hypothesised: 1) significant correlations between MOQ-T scores and higher-order visuo-spatial skills [28]; 2) age would be associated with MOQ-T scores [27,29]; 3) there would be a significant correlation between MOQ-T scores and a writing speed measure [16]; and 4) children with poorer motor skills and at risk of DCD (i.e., as identified through MOQ-T) were expected to be slower writers [16], exhibit poorer higher-order visuo-spatial functions [12,13,29], and reduced performance of the postural control system (i.e., impaired static balance [10]). Finally, because previous studies on the subject were lacking, no further a priori predictions were made regarding the relationship between objectively assessed balance performance (see the Material section) and MOQ-T scores.

2. Method

2.1. Participants

One hundred and fifty-six school-aged children, 89 females and 67 males (M_{age} = 9.1 years, SD = 12.7 months, age range: 8.4 years–11.3 years) attending the 2nd (n = 40), 3rd (n = 43), 4th (n = 44), and 5th (n = 29) grades were recruited in several public primary schools located in the metropolitan area of Cagliari (Italy). All the participants did not exhibit sensory or intellectual deficits, specific learning disabilities (i.e., certified according to the current Italian law n° 170/2010), or socio-cultural disadvantage, and they were free of motor impairments. None of the pupils was diagnosed with DCD.

Male and female participants were equally distributed across the classes ($\chi^2 = 3.641$, df = 3, p = .303), as well as gender was counterbalanced across the children ($\chi^2 = 3.103$, df = 1, p = .08).

Finally, the teachers of our participants were involved in the completion of MOQ-T which will be illustrated in the Materials section.

Ethical approval

This study was conducted in conformity with the provisions of the Declaration of Helsinki. The Ethics Committee of the University of Cagliari, protocol number 0001470, approved the protocol used in the current study. Moreover, the heads of the schools approved the procedure for the data collection. All participants agreed to voluntarily participate in the study, and prior written informed consent was given by the parents of the children involved in this investigation.

3. Materials

Each participant completed the following battery of tests:

The Raven Coloured Progressive Matrices test (CPM, [32]; Italian version [33]) is a measure of fluid intelligence that was proposed to evaluate visuo-spatial abstract reasoning skills and exclude the occurrence of intellectual deficits. The task consists of the selection of a visuo-spatial stimulus among six alternatives to complete a coloured geometrical pattern or a series of elements according to some logical principles. One score was assigned to each correct response (maximum total score = 36). The test's coefficient alpha is .909 [32].

The Five-Point Test ([34]; Italian version [35]) is a measure of executive functioning since it assesses visuo-spatial fluency. Specifically, each participant had to draw as many geometric patterns as possible by connecting 2–5 points provided in 40 matrices. To perform this task, participants had to respect two rules: First, the same geometrical pattern could not be repeated (i.e., perseveration error); second, a drawn line had necessarily to connect two points (i.e., rule-breaking). Thus, this task lets us assess both cognitive flexibility and strategic performance since the child has to produce as many novel geometric configurations as possible, paying attention to inhibit those already drawn and avoiding rule-breaking. As suggested by Stievano et al. [35], 3 min were given to complete the task. One score was assigned to each unique geometrical pattern produced that respected the two above-mentioned rules. The total number of correct responses was calculated (maximum score = 40). The test's coefficient alpha is .80 for the correct responses [34].

The 4-C Subtest (BVSCO–4C) is included in the battery for the Assessment of Writing and Orthographic Competence-2 developed by Tressoldi et al. [36] and it was used to evaluate writing speed. Each child was given a sheet and was asked to write as fast as possible the name of the Italian numbers in their cardinal order (e.g., 'uno, due', and so on) within 60 s. The total number of graphemes correctly written was computed. The test-retest reliability of this task is 0.702 [36].

MOQ-T ([27], Italian version [28]) is a screening tool to detect the possible occurrence of DCD. Following Schoemaker et al. [27], Giofrè et al. [28,29] reported that the factorial structure of the Italian version of MOQ-T encompasses two first-order factors (reflecting motor and handwriting skills), which are influenced by a second-order factor (general motor factor). Overall, the tool was proposed to the curricular teachers of our participants to collect further information on the motor profile of the pupils. Specifically, this tool encompasses 18 items assessing the degree of efficiency of general gross and fine motor skills and visuo-motor coordination engaged in a set of daily activities such as writing, and taking a ball. For each item teachers had to rate the frequency of occurrence of the behavior described along a 4-point Likert scale ranging from 1 (never true) to 4 (always true). The sum of the scores expressed in all 18 items was computed (maximum total score = 72). It must be noticed that a higher score suggests a higher probability of DCD. Following Giofrè et al. [28], a MOQ-T score ≥97.5 percentile (i.e., - 2 SD) indicates a significant risk of DCD occurrence. The internal consistency of this measure is α = 0.95 [29], therefore the Italian adaptation of this tool is reliable. In addition, the concurrent validity of MOQ-T has been reported by Giofrè et al. [29], according to which children with high MOQ-T scores also exhibited poorer visuo-spatial working memory, praxic and ideomotor skills (which were objectively assessed through a battery of tests). Moreover, there is evidence of the discriminant validity of MOQ-T, that is, children with poorer motor skills exhibited higher MOQ-T scores than TD children [27] 2008). Furthermore, the impact of age on MOQ-T scores has been shown by Giofrè et al. [28] (for a review of the validity of MOQ-T, see also [27,29]).

Balance abilities under static conditions, which reflects the overall performance of the postural control system, were quantitatively assessed by means of postural sway measurement, based on the analysis of the Center of Pressure (COP) time series acquired using a pressure plate (FDM-S, Zebris Medical GmbH, Germany). This device, which was previously employed in similar studies on school-aged children [37–39] is composed of 2560 capacitive sensing elements arranged in a 64 × 40 matrix and connected via a USB interface to a Personal Computer. Children were asked to stand barefoot, as still as possible for 30 s, on the plate having the foot placed on a sheet of paper with two footprints oriented at approximately 30°, keeping a stable and relaxed position with arms freely positioned along their sides and their gaze fixed on a target image. This test was administered three times under two conditions, namely in the presence and absence of visual input (Eyes Open, EO, and Eyes Closed, EC, respectively), in random order. The raw COP time series were low-pass filtered (10 Hz cutoff; 4th order Butterworth; bidirectional) and then post-processed with a custom-developed Matlab® routine to calculate the sway area (95% confidence ellipse) and COP path length, that is the overall distance traveled by the COP during the trial. The interpretation of such parameters is quite straightforward, as larger sway areas and longer trajectories followed by the COP during the trial are indicative of the worse overall performance of the postural control system (sway area) and more frequent muscular corrections to achieve stability (COP path length). The mean value obtained by the three trials carried out for each condition was considered representative of a certain participant and then used in the subsequent analysis.

3.1. Procedure

In order to take part in the study, written informed consent had to be provided by the parents of each participant before the experimental testing.

Relatively to the psychological measures, pupils were collectively evaluated in one experimental session that was conducted in their classroom. The presentation order of the tests was counterbalanced across the classes according to the Latin square procedure. Each session lasted approximately 45 min. Moreover, the objective assessment of static balance through the sway analysis was individually performed in a silent room of the school before or after the psychological assessment and it lasted approximately 5 min.

Finally, the teachers of each participant completed MOQ-T during their weekly meeting. This approximately required 5 min. Fig. 1 illustrates the phases that characterized the realization of this study.

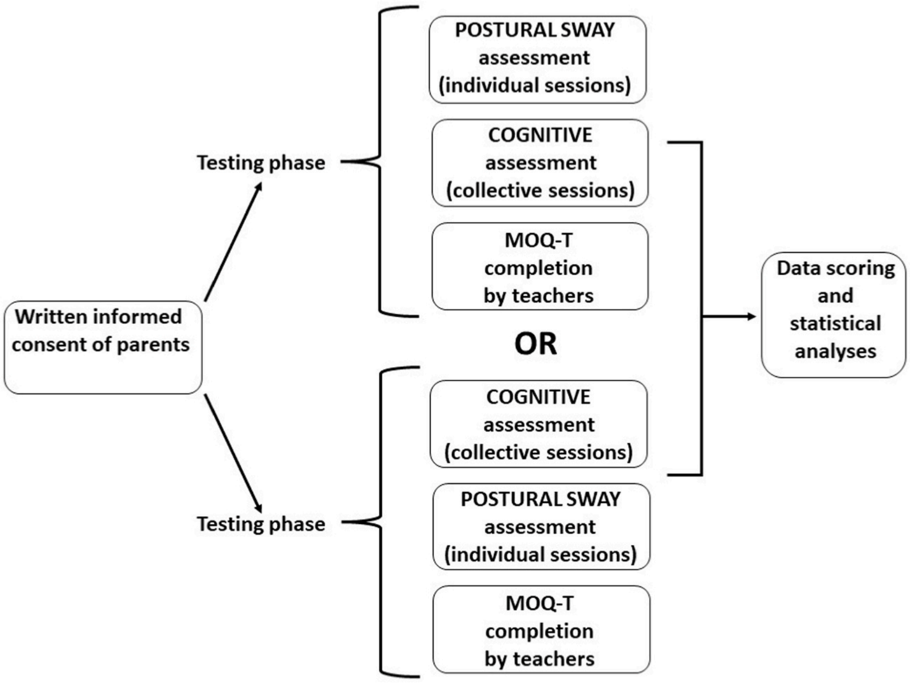

Fig. 1. Illustrates the phases underpinning the realization of the study. Once the heads of the schools and teachers expressed their will to take part in the study, written informed consent was provided by the parents of the participants. Therefore, a sample of 2nd-5th graders performed some psychological (The Five Point Test, Raven Coloured Progressive Matrices Test, and 4-C Subtest of the BVSCO) and motor (i.e., balance abilities) tests, and their teachers completed the MOQ-T test. Finally, data scoring and statistical analyses were performed.

3.2. Statistical analyses

An a priori power analysis using the G-power program [40] indicated that to perform two-tailed correlational analyses, a convenient sample of 138 people would be needed, when r = 0.3, power = .95, with alpha at .05. Furthermore, to perform a regression analysis using 8 predictors, with 90% power, alpha at .05, and moderate effect size ($f^2 = 0.15$), an a priori power analysis established that 136 participants would be needed.

The data were analyzed using IBM SPSS Statistics version 24 (SPSS Inc., Chicago, IL, USA). Statistical significance was set to p-values $< .05$. Descriptive statistics were performed to illustrate the characteristics of the sample. Pearson correlations among MOQ-T scores, age of participants, and objectively assessed motor and cognitive measures were performed to check for multicollinearity and to test the nature of the associations between the variables. In addition, based on the results of the correlational analyses, a hierarchical multiple regression analysis performed by ordinary least squares estimation was carried out to explore which factors predicted MOQ-T scores. Furthermore, using the Italian normative data for MOQ-T, participants at risk of DCD were identified.

4. Results

First, a series of Pearson's coefficients were computed to examine the nature of the associations between MOQ-T scores, age, and each motor and cognitive measure. Table 1 summarizes these results.

As reported in Table 1, the associations among the variables cannot be considered high (i.e., $r \geq 0.9$), therefore multicollinearity among them was excluded.

Then, based on the findings of the correlational analyses, a hierarchical regression analysis was performed to examine which factors predicted MOQ-T scores. Preliminary analyses were carried out to ensure no violation of the assumptions of normality, linearity, and homoscedasticity. In addition, tests to verify if the data met the assumption of collinearity indicated that multicollinearity was not a concern. Age was entered at Step 1, accounting for approximately 4% of the variance in MOQ-T [$F (1,139) = 6.722$, $p = .011$]. When COP Path length EO, Sway Area EO, and Sway Area EC were added at Step2, 11% of the variance relative to MOQ-T scores [Adjusted $R^2 = 0.11$, $F (4,136) = 5.377$, $p < .0001$] was predicted by age ($B = -0.124$, $SE = 0.52$, $\beta = - 0.194$, 95% CI [- 0.226, -0.022], $t = -2.405$, $p = .018$) and the Sway Area EO parameter ($B = 0.016$, $SE = 0.005$, $\beta = 0.32$, 95% CI [0.006, 0.026], $t = 3.147$, $p = .002$). Moreover, CPM, Five-Point, and Writing Speed (i.e., BVSCO–4C) measures were entered at Step 3. It was found that the total variance explained by the model as a whole was approximately 26% [Adjusted $R^2 = 26.2$, $F (7,133) = 8.1$, $p < .0001$], and the significant predictors were the Sway Area EO parameter ($B = 0.014$, $SE = 0.005$, $\beta = 0.275$, 95% CI [0.004, 0.023], $t = 2.297$, $p = .004$), 5 Point ($B = - 0.358$, $SE = 0.113$, $\beta = - 0.245$, 95% CI [- 0.582, - 0.135], $t = - 3.175$, $p = .002$), and BVSCO–4C ($B = - 0.104$, $SE = 0.029$, $\beta = - 0.34$, 95% CI [- 0.162, - 0.046], $t = - 3.54$, $p = .001$) scores. Table 2 illustrates these results.

Finally, after the application of the cut-off normative data for the Italian version of MOQ-T [28], participants with very low motor skills at risk of DCD (i.e., performance ≥97.5 percentile) were identified. Specifically, a subgroup composed of 7 pupils (i.e., 2 males and 1 female attending the 3rd grade, and 3 males and 1 female attending the 4th grade, approximately 4.5% of the sample) was identified. When we analyzed the psycho-motor profiles of these participants, the evaluations expressed by their teachers was consistent with the assessments carried out through objective tests. That is, two male pupils with very poor motor skills identified through MOQ-T also exhibited worse postural sway parameters, were slower in the writing (i.e., – 2 SD performance on the BVSCO–4C subtest), and displayed less cognitive flexibility (i.e., score <10 percentile on the Five-Point Test). Moreover, the remaining 5 participants with very high MOQ-T scores reported poorer writing speed and/or poorer visuo-spatial reasoning skills (i.e., score ~ 25–30 percentile on the CPM task), and displayed less visuo-spatial fluency skills (i.e., score <10 percentile on the Five-Point Test).

5. Discussion and conclusion

DCD is a complex neurodevelopmental disorder that may significantly impact academic achievement, therefore its early identification through the application of reliable and valid tools is essential to support school-aged children who are at risk or who already

Table 1
Pearson's correlations between MOQ-T scores and age, postural sway (i.e., Sway Area EO for EO, COP Path Length EO, Sway Area EC, and COP Path Length EC, where COP means Center of Pressure, EO means Eyes Open, and EC means Eyes Closed), Raven Coloured Progressive Matrices (i.e., CPM), 5 Point (i.e., Five-Point Test), and writing speed (i.e., BVSCO–4C) measures, respectively.

	1	2	3	4	5	6	7	8	9
1. MOQ-T	–								
2. Age	−0.235**	–							
3. Sway Area EO	0.314***	−0.092	–						
4. COP Path Length EO	0.210**	−0.264***	0.621***	–					
5. Sway Area EC	0.182*	−0.110	0.490***	0.793***	–				
6. COP Path Length EC	0.142	−0.120	0.510***	0.853***	0.748***	–			
7. CPM	−0.223**	0.273**	−0.050	−0.038	−0.035	−0.022	–		
8.5 Point	−0.344***	0.240***	−0.115	−0.095	−0.009	0.063	0.160*	–	
9. BVSCO–4C	−0.348***	0.624***	−0.038	−0.080	−0.016	−0.041	0.272***	0.268***	–

Note. *p < .05, **p < .01, ***p < .001.

Table 2
Summary of a hierarchical regression analysis for motor deficits assessed through the Italian version of MOQ-T.

Dependent Variable	Predictor	B	95% CI for B		SE B	β	R^2	ΔR^2
			LL	UL				
	Step 1						.04	.04
MOQ-T	Constant	38.055***	26.594	49.516	5.797			
	Age	−0.138*	−0.243	0.033	0.053	−0.215		
	Step 2						.011	.07**
	Constant	34.234***	21.830	46.637	6.272			
	Age	−0.124*	−0.226	0.022	0.052	−0.194		
	COP Path Length EO	−0.006	−0.024	0.012	0.009	−0.107		
	Sway Area EO	0.016*	0.06	0.026	0.005	0.32		
	Sway Area EC	0.002	−0.005	0.009	0.004	0.086		
	Step 3						.26	.15***
	Constant	27.760***	14.596	40.935	6.661			
	Age	0.072	−0.050	0.194	0.062	0.112		
	COP Path Length EO	- 0.003	−0.019	0.014	0.008	- 0.049		
	Sway Area EO	0.014**	0.004	0.023	0.005	0.275		
	Sway Area EC	0.002	−0.004	0.008	0.003	0.082		
	5 Point	−0.358**	- 0.582	- 0.135	0.113	- 0.245		
	CPM	- 0.178	- 0.438	0.082	0.132	- 0.103		
	BVSCO–4C	- 0.104**	- 0.162	- 0.046	0.029	- 0.340		

Note. CI = confidence interval; LL = lower limit; UL = upper limit.
COP = Center of Pressure; EO = Eyes Open; EC = Eyes Closed; 5 Point = Five-Point Test; CPM = Raven Coloured Progressive Matrices; BVSCO–4C = writing speed.
*p < .05; **p < .01; ***p < .001.

exhibit this condition [1]. This is very relevant given that thus far, DCD is underestimated and its prevalence is not widely acknowledged [23].

To the best of our knowledge, the present study is the first to have examined the relationship between MOQ-T scores and objectively assessed measures of writing speed, fluid intelligence, visuo-spatial fluency, and postural control system performance.

As with previous studies, small to moderate statistically significant correlations were found between MOQ-T scores and age [27,29], writing speed [16], and visuo-spatial fluency [13]. Moreover, in accordance with previous evidence confirming the relationship between MOQ-T scores and active visuo-spatial working memory skills [12,29], a significant correlation was also found between fluid intelligence scores and the MOQ-T index. However, from our perspective, the most innovative finding of the present study was the significant association between MOQ-T scores and balance performance, as expressed using the main sway parameters. As was noted above, the efficiency of the postural control system has a direct impact on a large variety of motor skills and motor coordination (which is a central element of the MOQ-T questionnaire), and it has been hypothesised that it plays a crucial role in ensuring postural stability [41,42]. Moreover, previous studies found a significant association between MOQ-T scores and performance in the Movement Assessment Battery for Children (which includes static and dynamic balance tasks) [27]. Our results are consistent with these findings, indicating that MOQ-T has the capacity to identify children who exhibit some kinds of alteration in the maturation of their postural control system. To the best of our knowledge, no previous studies have systematically correlated the subjective perceptions of teachers regarding coordination with objective biomechanic parameters of postural control. However, it is worth noting that an association between objective measurements of balance teachers' (or parents') evaluations of the way children use sensory information in their natural environments (as indicated by the Sensory Processing Measure, [SPM], a questionnaire designed to help the identification of sensory processing difficulties in 5−12-year-old children [43]) has been recently proposed [44]. Moderate correlations (Spearman's rho between 0.30 and 0.40) were found between several sway parameters and the balance subtest scale score of the SPM questionnaire, thus supporting the argument that parent-teacher reporting is a reliable input alert for further testing (to uncover possible subtle postural control difficulties).

Furthermore, the current findings also demonstrate that a significant proportion of variance in MOQ-T is predicted by writing speed, visuo-spatial fluency, and Sway Area OA. Writing speed as a significant predictor of MOQ-T scores was not surprising, since one of the factors encompassed by the questionnaire is related to hand-writing skills [27,29]. By contrast, our regression analysis complements previous findings [29], by pointing out that higher-order visuo-spatial processes involving cognitive flexibility, inhibition, and strategic control (i.e., non-verbal fluency) played a crucial role in predicting a set of motor-related daily activities performed at home or in school by the participants. However, again complementing previous studies on the association between MOQ-T scores and gross and fine motor skills [24,30,31], the current outcomes also revealed that approximately 7% of the variance in the MOQ-T condition was predicted by sway area in the presence of visual input. Sway area is a parameter representative of the overall performance of the postural control system [45] that in children tends to decline with increasing age until full maturation of the postural control system is reached. It is also rather sensitive to alterations associated with conditions that impact overall motor coordination. For instance, significantly larger sway areas have been observed amongst children with DCD [10], autism [46], or ADHD [47] than amongst their TD counterparts. Our results suggest that continuous and daily observations by teachers of the motor performance of their pupils can be used, to some extent, to identify postural control issues. Consistent with this, it was also found that children at risk of DCD (identified through MOQ-T) displayed significant deficits in writing speed, visuo-spatial fluency, abstract reasoning, and/or sway parameters. Therefore, given that none of the participants had been diagnosed as having DCD, it can be concluded that (as per other DCD tools used by parents; e.g. Ref. [48]), MOQ-T is a reliable and valid DCD clinical screening tool for pupils attending primary school.

Altogether, embracing an applied viewpoint, two conclusions can be drawn from the findings. First, while teachers in Italy do not have sufficient access to the tools required to identify children at risk of DCD [28], MOQ-T—a valid open-source instrument—could be used with benefit in primary school. Its wider application would facilitate the early identification of children with suspected motor deficits (and, therefore, those with specific educational needs). Second, it is strongly recommended that when the motor development of school-aged children is screened at school, a multidisciplinary perspective involving teachers (who spend many hours per day at school with their pupils), school psychologists (who understand the effects that conditions such as DCD can have on academic performance), and biomedical engineers (who specialise in the biomechanical analysis posture and movement and can therefore quantitatively assess basic motor skills development) should be assumed. The implementation of these suggestions (i.e., combining observations by teachers with cognitive and biomechanical assessments) would generate more comprehensive psycho-motor profiles of those pupils who might need a person-centred psychoeducational intervention.

However, this study must be considered exploratory, and it requires further research. Therefore, several limitations need to be discussed. For instance, the sample size and battery of tests were small in number. In addition, no developmental trends in the cognitive and motor measures were investigated, especially amongst the subsample of participants at risk of DCD. Therefore, in future researchers should face these issues, they might replicate the study using larger samples and a more exhaustive battery of motor tests (e.g., including further measurements of basic motor skills such as gait and functional mobility) and cognitive verbal and visuo-spatial tasks (e.g., assessing text comprehension, updating, and imagery skills required in the study of geography learning). Finally, future research might clarify whether children at risk of DCD also satisfy the criteria for visuo-spatial learning difficulties, since a partial overlapping between these two neurodevelopmental conditions has been hypothesised [19].

Author contribution statement

Maria Chiara Fastame: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Eleonora Spada; Demetra Cimmino; Bruno Leban; Micaela Porta; Federico Arippa; Giulia Casu: Performed the experiments.

Massimiliano Pau: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

The authors do not have permission to share data.

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Availability of data and material

The data that support the findings of this study are not publicly available due to privacy or ethical restrictions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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