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Effect of a vestibular-stimulating training program on motor skills in conjunction with cognitive aptitude of young school-aged children

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Abstract

Introduction. The current study was conducted to evaluate the effects of the Minds-in-Motion *Maze* program on motor and cognitive abilities in school-aged children.

Methods. The experimental design used was a randomised controlled trial. Participants, belonging to a public primary school, were 100 young children (50% boys) ranging from 6.00 to 8.50 years old (7.32 ± 0.82 years in average). They were randomly assigned to experimental and control groups (50 subjects/each), and two dropped out from each group. While the control group received unstructured physical activity, the children in the experimental group engaged in the Minds-in-Motion *Maze* vestibular stimulation program (24 weeks of a 30-minute structured PA on a daily basis). A pre- and post-test were conducted to evaluate the performance in motor skills and cognitive ability using the Bruininks-Oseretsky Test of Motor ProficiencyTM Second Edition, complete form and Wechsler Intelligence Scale for Children, Fourth Edition.

Results. The analysed data indicated that engaging in Minds-in-Motion Maze activities positively influenced the motor and cognitive abilities among the children. The between-group analysis exhibited strong significant improvement in the experimental group compared to the control group ($p < 0.05$), which did not show significant development. Boys outperformed girls on most tests, notably as age increased. The within-groups analysis (experimental group) demonstrated significant differences in the post-intervention gains of all motor and cognitive parameters ($p < 0.05$).

Conclusions. Taken together, the current results reinforce causal evidence for the effects of Minds-in-Motion *Maze* based physical activity on improving both motor skills and cognitive aptitude in school-aged children.

Key words: physical activity, motor skills, cognitive ability, vestibular system, Minds-in-Motion *Maze*, school-aged children

Introduction

Childhood is a critical stage for human development, which could change the long-term course of life to a significant degree. It contributes to the development of many aspects of healthy behaviours that are necessary for building physical, cognitive and socio-emotional contexts [1].

In recent years, unfortunately, there has been a shift in the lifestyles of children, especially in their late childhood. Unlike children of previous decades, children today live in a world of digital technology, which has become an integral part of our daily life. However, little is known about its implications for children from different backgrounds. Indeed, competing time demands in the curriculum have also left physical activity (PA) as a low priority among schools. Collectively, they are leading increasingly sedentary lifestyles/behaviours that involve spending more time indoors engaged in screen-based activities, while their time outside the home is increasingly focused on structured, supervised activities as a part of ongoing parental concerns for their safety. The significance of studies on the positive impact of PA [2], together with the negative impact of sedentary lifestyles [3] is warranted, given its importance on the public health [4] including physical, mental and cognitive domains [1].

Physical activity is deeply anchored in our biological heritage, which develops across childhood and adolescence. It is fundamental to strengthen the early development of each child. Essentially, physically active children and adolescents are likely to be physically active during adulthood and throughout their lives [5]. The development of competency in a range of fundamental motor skills (MSs) during childhood may help to establish a lifelong commitment to PA [6].

Engaging in regular PA, which results in intense energy expenditure, is considered an effective guarantee against the risk of somatic illnesses and pathological behaviours [7, 8]. Energy expenditure is the reference for PA under free-living and unrestrained conditions for humans in their natural surroundings [9]. There is well-documented theoretical and practical evidence that higher levels of PA in school-aged children are associated with vital short- and long-term health benefits in the physical, biological, psychological, motor behavioural, emotional, social, cognitive, and academic performance domains [10–14]. Interestingly, PA plays a critical role in promoting a beneficial gene-expression profile [15]. Paradoxically, PA leads to various health risks, including posture problems, somatic conditions, problems with circulation, overweight and obesity, accelerated biological ageing, premature death, and the list goes on [16].

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There is much published research on the relationship between PA and motor skill (MS) in children. The literature has acknowledged such a relationship-specific connection and attributed it to enhanced specific brain organs in conjunction with the vestibular system [17]. It was confirmed that promoting PA in early childhood, especially in young schoolers, could help develop both fine and gross MSs [18]. Motor skill competence further predicts PA behaviour in this segment of young children [19]. This postulation is reiterated by evidence showing a reciprocal relationship between PA and motor development. As a very dynamic relationship, motor competence increases the likelihood of participating in PA, while engaging in PA provides opportunities to develop motor competence [20]. An increasing amount of evidence suggests that children who are less physically skilful tend to be less active than their skilful counterparts [21]. Additionally, children with better-developed MSs may find it easier to be active and engage in more PA than those with less-developed MSs [22]. A similar finding was made by Webster et al. [23]; that children with higher fundamental MSs tend to engage in greater amounts of PA and girls were shown to be at a deficit compared with boys in regards to both PA and fundamental MSs. A very recent study, however, revealed a weak cross-sectional correlation of motor competence with PA in early childhood (two to six years), suggesting that motor competence and PA developed independently of each other during this young age and neither is predictive of the other [24]. The previous authors hypothesised that the relationship between MSs and PA strengthens as children age.

In fact, MSs in children are considered to be associated with various health outcomes that affect child development, such as adiposity, self-esteem, emotional well-being, cardiorespiratory fitness, and cognition [25]. Accordingly, developing and implementing effective interventions to improve children's MSs have become a priority. Research involving a wide range of arguments shows evidence that the development of MSs and cognitive ability are malleable and tend to be connected [26]. The significant advances made in recent years in neuroscience have provided substantial insights into connecting MS/PA to brain structure/function, and cognitive development [27–29]. Domain-based reviews indicate that both cognitive and motor functions are controlled by areas of the brain, in particular the frontal lobe, corpus callosum, cerebellum and basal ganglia, which collectively interact to exercise judgement and control over executive function and intentional movements, which require anticipation and prediction of movements [30]. Some reported that the influence of PA on cognition is partially due to the physiological changes established in the body. There may also be a causal link behind the fact that both motor and cognitive skills follow a similar developmental timetable with an accelerated development between five and ten years of age [31].

Minds-in-Motion *Maze* (M-i-M *M*) is a promising, low-cost PA program designed to enhance functions of the vestibular system; the organ of balance inside the inner ear. It provides help to students of all ages in an innovative way via increasing attention and concentration. Evidence-driven facts with specific benefits to the academic, social, behavioural, physical, and MS domains were also well-documented [32, 33]. The M-i-M *M* premise is that there is a link between early afferent neural stimulation and cognitive abilities [34].

Essentially, the M-i-M *M* has been developed to integrate the two hemispheres of the brain and improve neural integration such as balance and coordination (*e.g.*, eye-hand, eye-foot and bilateral limbs) through movements (*e.g.*, balancing, rolling, pushing, pulling, stomping and jumping) that focus on vestibular stimulation. The *Maze* approach also includes health-related aspects such as muscular strength and endurance, flexibility and cardiovascular endurance. This program is comprised of four concentrations (*i.e.*, balance training, core strength development, auditory therapy and vestibular circuit training) with goal-directed motor activities to provide motor development for increased sensory processing (visual and auditory) and integration [34]. According to the little published research, the M-i-M *M* program has achieved remarkable results in motor- and cognitive-related domains [32, 33].

The objective of the current study is to examine the influence of M-i-M *M*-based activities in fostering MSs and cognitive ability in young school-aged children and to place the findings within the larger context of the role of non-perceptual factors such as age, sex and sex-age on the results obtained.

Subjects and methods

Medical ethical statement

The study protocol was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University, Egypt on 15/7/2018 (No: P.T. REC/012/002010), and complies with all international regulations concerning the ethical use of human volunteers for research studies. Participation was voluntary for the school administration, parents of all children, and the children themselves. First, oral consent was obtained from the school director before the commencement of the study. Then, parents of all the children and their teachers were informed during an information meeting and handed a written information letter, accompanied by the opportunity to object or opt-out. Written consent was obtained later from both of school director and children's parents or legal guardians permitting involvement after confirming that data would be analysed anonymously for the purpose of privacy protection.

Procedures

A pre-post study, which measures the occurrence of an outcome before and after receiving a structured PA program, was implemented over a period of six months (24 weeks) from October 2018 to March 2019 on school-aged children.

One public primary school (Dsons Umm Denar School for Basic Education, Damanhour, El-Buhayra Governorate, Egypt) was chosen for the study. The main criterion of this choice was the school's belief in the aims of the study and its enthusiasm to see its effect on the children's success.

Initially, motor and cognitive competences were assessed at baseline using two comprehensive standardised tests (Bruininks-Oseretsky Test of Motor Proficiency™ Second Edition, complete form – BOT™-2 CF; and Wechsler Intelligence Scale for Children, Fourth Edition – WISC-IV) following the necessary instructions for each task in both scales. Separately, the children recruited to the experimental group (EG) were subjected, on a regular basis, to a structured (moderate to vigorous) PA program (M-i-M *M*). They were trained collectively on the same day for the stipulated period of the intervention. The untreated group (EG) was allowed to participate in regular PAs concurrently. Immediately after completion of the treatment intervention, all children were re-evaluated for their motor and cognitive abilities. Children's training and test scoring were performed by the authors themselves according to strict protocols.

All the tests and training sessions took place in the school environment; during school break time (11:30 a.m. – 12:00 p.m.) or instead of physical education classes. The training/test area (a familiar room with ample space and sufficient light, approx. 47 feet by 35 feet and free of possible distractions) was chosen because it would be comfortable for the children and accommodate all the test and intervention items. A well-tested design and calibrated equipment were used.

Participants and setting

The sample of children consisted of 100 young school-aged children ranging in age from six to eight. The children were randomly selected without considering any characteristics beyond the listed criteria. The sample was restricted to normal, healthy individuals. It did not include any children who were known to have any conditions such as mental or neurological impairment, orthopaedic condition, metabolic disease, vestibular dysfunction, hearing problem, locomotor disorder, or concurrently receiving therapy. Specifically, children with (a) severe physical impairment, (b) a learning disability, or (c) below normal intelligence were excluded from the study owing to the findings by Bruininks and Bruininks [35] that subjects exhibiting these conditions perform worse on the BOT™-2 CF.

The anthropometric characteristics of the children (*i.e.*, height, weight and body mass index – BMI) were estimated in a group setting during regular classes. Height was measured to the nearest 0.1 cm with the child standing with erect posture and without shoes using a portable gauge (Seca portable stadiometer). The weight was taken with minimal clothing and recorded to the nearest 0.1 kg using an electronic scale. The BMI based on self-reported height and weight was computed as a function of weight (in kg) divided by height (in m^2) and expressed in kg/m^2 [weight (kg)/height^2 (m^2)].

Considering both sexes, the children were randomly divided into two equal groups (50 children/each) namely the experimental group (EG), participating in the sensory M-i-M *M*, and the control group (CG), continuing with normal school activities. Over the course of the trial, a number of subjects dropped out of both groups (two/each) for various reasons and their data were excluded from all analyses.

Since this study includes both an intervention study and program evaluations, the methodology/methods section is divided into two major parts for clarity. The intervention will be described first, followed by the program evaluations.

Intervention strategy

Experimental group

For the purpose of this study, the M-i-M *M* was employed as a promising, innovative program that provides help to students of all ages. This program has distinctive features and advantages. First, the structured PA program was uniquely designed to promote the integration of the two hemispheres of the brain through movements that focus on vestibular stimulation, in a sense incorporating physical and mental stimulation. Second, it is a structured program specialised in the needs of social interaction and communication and has multiple health benefits related to strengthening balance, coordination, muscles and endurance, flexibility and cardiovascular endurance [34].

Targeting the primary sensory pathways of the vestibular system, the M-i-M *M* program is comprised of four concentrations with goal-directed motor activities, including balance training, core strength development, auditory therapy, and vestibular circuit training. The program approach consists of 15 different movements designed in stations to provide motor development for increasing sensory/visual processing and integrating MS [34].

Over a six-month period (two academic semesters), children in the EG received a 30-minute session, five times a week, from Sunday to Thursday. All children were safely escorted to the assigned training area one-on-one. The participants went through the stations individually to minimise distractions. Children begin the *Maze* at various stations and move in a clockwise manner. Each child performed the exercises at their specific station for one minute before rotating to the next station. Each week, the *Maze* was increased in intensity for each exercise. Exercises included in the *Maze* were as follows: strong arm push; eye can convergence; eye to eye; the beam team; jelly roll; puppy dog crawl; monster mash; climb every mountain; balance board bash; electric slide; skip to my lou; cross walk; bean bag boogie; jumping jack flash; and step back.

Control group

While the treated group (EG) received structured PA using the M-i-M *M* program, the CG participated in their typical, unstructured PA in the classroom or playground according to the regular schedule of the school's physical education. The children (including the experimental group) were allowed to play with balls, practice running proficiently, climb stairs and go on slides. Children's play activities continued without receiving specific instructions from the authors.

Administrating and scoring assessments

Instruments

Two instruments were used to measure the outcomes on motor and cognitive competences of the children.

The level of motor proficiency was assessed by the BOT™-2 CF testing battery relative to the changes from baseline; main outcome variables from pre- to post-intervention. BOT™-2 CF is a norm-referenced standardised test designed to assess fine and gross MSs for children and individuals aged between 4 and 21 years [35, 36]. The children were tested using the complete form of the BOT™-2 CF, which is available with four composite areas [*e.g.*, (a) fine manual control, (b) manual control, (c) body control, (d) strength and agility] and eight subtests [*e.g.*, (1) fine manual precision, (2) fine motor integration, (3) manual dexterity, (4) upper-limb coordination, (5) bilateral coordination, (6) balance, (7) running speed and agility, (8) strength]. Each sub-test includes six to seven items, with a total of 53 tasks [35].

Motor-area composites were reported as standardised scores ($M = 50.0$, $SD = 10.0$), and subtest scores were reported as scale scores ($M = 15.0$, $SD = 5.0$). Descriptive categories were defined as 'well-above average' (standard score ≥ 70; scale score ≥ 25; ≥ 98th percentile); 'above average' (standard score 60 to 69; scale score 20 to 24; 84th to 97th percentile); 'average' (standard score 41 to 59; scale score 11 to 19; 18th to 83rd percentile); 'below average' (standard score 31 to 40; scale score 6 to 10; 3rd to 17th percentile); and 'well-below average' (standard score ≤ 30; scale score ≤ 5; ≤ 2nd percentile) [35].

The BOT™-2 CF was chosen in our study because it is one of the most comprehensive assessments for motor proficiency worldwide. It evaluates a diverse range of MS and is frequently used in the international diagnostic guidelines, and in research studies of functional capacity in children and school-age young adults as a reliable assessment tool [36].

The cognitive ability of children was evaluated using the WISC-IV [37], a widely used standardised intelligence scale assessing multiple components of intellectual ability in children aged six to 16 years. The WISC-IV leads to a better understanding and more valid information on the general intellectual, cognitive and learning abilities.

The WISC-IV typically takes 60–90 minutes to complete. It generates a Full-Scale IQ (FSIQ) and four index score IQs as a measure of general intellectual functioning. These IQ scores all are set with a mean of 100 and a *SD* of 15. Each of the subtests uses a mean of ten and a standard deviation of three. The scale consists of four composite areas recognised as master subscales [*e.g.*, Verbal Comprehension (VC), Perceptual Reasoning (PR), Working Memory (WM) and Processing Speed (PS)] that provide the four index scores – (VCI), (PRI), (WMI), and (PSI) – thought to represent the major components of intelligence. Although the full version of the WISC-IV has 15 subtests, only ten are considered core and used more often when testing intelligence [37]. The FSIQ and the four indices, as well as the subtests, have been shown to have excellent reliability (*i.e.*, internal consistency and test-retest), validity and stability [38].

Measurements

Motor proficiency

The eight relevant BOT™-2 CF subtests were administered individually to the children at eight different stations. The BOT™-2 CF requires 40–60 minutes per child. The children were brought to the test area from their classroom by grade level separately. The children moved through the subtests, test items in an orderly manner, as in the BOT™-2 CF record form, starting with the tasks related to fine motor precision and finishing with strength tasks, since reversing the application order could compromise motor performance in certain tasks due to tiredness and/or fatigue. Each subtest was rigorously administered according to the instructions and guidelines provided in the examiner's manual.

The BOT™-2 CF provides a total motor composite score, which is an overall measure of fine and gross motor proficiency. On the BOT™-2 CF record form, participants receive a raw score for each test item, which is transformed into a common value called a point score. This conversion of a raw score into a point score allows for the calculation of a total point score from the sum of all test items within each subtest. The total point score is further transformed into a scale score, then a standard score considering age and sex. The total motor composite score is derived from the fine manual control, manual coordination, body coordination, and strength and agility composite scores, which in turn are derived from the fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper-limb coordination, and strength subtest scores.

All data were hand scored on the given BOT™-2 CF form in accordance with the BOT™-2 CF manual [35] and then transcribed into the SPSS statistical package program.

Cognitive efficiency

Out of the 15 WISC-IV procedures, only four subtests were considered (one from each composite area); those thought to have a robust connection with the vestibular functioning in this study to express the cognitive ability of the investigated children. This included the similarities, picture completion, digit span, and coding subtests. Similarities is a verbal comprehension task, which measures logical thinking or aptitude to reason logically, conceptual reasoning (*i.e.*, abstract reasoning) and verbal concept formation. Picture completion, a perceptual reasoning subtest, was developed to measure non-verbal reasoning and the ability to understand abstract visual information. The digit span, a working memory subtest from the WISC-IV, consists of two parts: digit span forward and digit span backward, with the main goal of assessing the short-term memory of children. It also measures attention, auditory processing, and mental manipulation. Coding, a subtest of processing speed subscale, measures the visual-motor dexterity, associative non-verbal learning, and non-verbal short-term memory [37, 38]. The children were examined individually, and the time required to complete the tasks ranged between 10 and 15 minutes for each child. Test administrations were carefully conducted according to WISC-IV guidelines. The row scores from each subtest were converted into scale scores ready for the statistical estimation of variance.

Experimental design

The randomised control-group pretest-posttest design, better known as a randomised controlled trial, or RCT, was used in this study. The design had both random selection (Table 1) built on a thorough representation of the different age categories of the three school grades, considering sexes and random assignment for two age- and sex-matched cohorts (experimental and control). The age groups were evenly divided into the two testing groups. A randomly generated sequence of numbers between one and two was used to allocate each participant into one of the two groups.

Sample size

Since we are not aware of any previous studies using the same intervention program with the same assessment tools and children's age, a power calculation for finite populations was carefully performed using data from a preliminary pilot study. This investigation was performed with a randomised sample of 15 children between the ages of 6–8 years prior to launching the main study. This power calculation with a 95% confidence level (two-tailed alpha of 5%) and statistical power (1-β) of 80% resulted in a required number of 42 participants for each group as an adequate sample necessary to execute the study. The number was increased to 50 participants for each group to allow for dropout and exclusion rates.

Statistical analysis

Descriptive and inferential statistics were used to assess the M-i-M *M* efficacy in terms of all the studied parameters. The data were collected, tabulated and entered into Microsoft Excel with each child's coded number in order to fit the proper formatting guidelines to be analysed by the statistical software program [Statistical Package for Social Sciences, version 18 (SPSS V-18)]. For the children's MSs, the data were scored using the age- and sex-normative tables derived from the original U.S. reference sample [35]. The scaled (*e.g.*, eight subtests) and standardised (*e.g.*, four motor-area composites and total motor area) scores from the BOT™-2 CF assessments at the children's initial and follow-up tests were analysed. The scale scores from similarities, picture

Table 1. Differences in basic demographic and anthropometric features of children under study (population-based cohort of 96 subjects)

Study groups			*N*	Baseline measurements (M ± *SD*)							
				Age (year)	Range (min–max)	Height (m)	Range (min–max)	Weight (kg)	Range (min–max)	BMI (kg/m²)	Range (min–max)
Participating groups		CG	48	7.32 ± 0.81	6.00–8.50	1.16 ± 0.07	1.01–1.27	23.95 ± 2.48	19.00–28.50	17.65 ± 1.23	15.84–20.23
		EG	48	7.32 ± 0.83	6.00–8.50	1.17 ± 0.06	1.05–1.26	23.52 ± 2.47	19.50–29.20	17.25 ± 1.16	15.41–19.88
		p-value	–	0.965	–	0.988	—	0.352	—	0.141	—
Sex effect		Boys	48	7.34 ± 0.82	6.00–8.50	1.17 ± 0.06	1.05–1.27	23.67 ± 2.58	19.50–28.50	17.27 ± 1.06	15.41–19.55
		Girls	48	7.30 ± 0.82	6.00–8.50	1.16 ± 0.07	1.01–1.26	23.80 ± 2.38	19.00–29.20	17.64 ± 1.31	15.84–20.23
		p-value	–	0.725	–	0.628	–	0.860	–	0.187	–
Age effect		6 years G1	32	6.34 ± 0.17	6.00–6.58	1.11 ± 0.04*BC*	1.01–1.15	21.24 ± 1.52*BC*	19.00–24.50	17.34 ± 1.32	15.41–20.23
		7 years G2	32	7.34 ± 0.22	7.00–7.75	1.15 ± 0.03*AC*	1.08–1.19	23.56 ± 0.94*AC*	22.30–25.40	17.82 ± 1.15	15.95–19.88
		8 years G3	32	8.27 ± 0.17	8.00–8.50	1.24 ± 0.03*AB*	1.20–1.27	26.40 ± 1.32*AB*	24.50–29.20	17.20 ± 1.07	15.94–19.46
		p-value	–	0.000	–	0.000	–	0.000	–	0.058	–
Sex-age effect	Boys	6 Y G1	16	6.35 ± 0.17*BC*	6.00–6.58	1.12 ± 0.03*BC*	1.05–1.15	20.86 ± 1.05*BC*	19.50–22.40	16.79 ± 0.93*	15.41–18.39
		7 Y G2	16	7.39 ± 0.22*AC*	7.08–7.75	1.15 ± 0.03*AC*	1.08–1.19	23.51 ± 0.78*AC*	22.40–24.60	17.76 ± 1.09	15.95–19.55
		8 Y G3	16	8.28 ± 0.17*AB*	8.00–8.50	1.24 ± 0.03*AB*	1.20–1.27	26.65 ± 1.12*AB*	22.40–28.50	17.25 ± 1.05	16.00–19.03
		p-value	–	0.000	–	0.000	–	0.000	–	0.071	–
	Girls	6 Y G1	16	6.33 ± 0.17*BC*	6.00–6.58	1.10 ± 0.05*BC*	1.01–1.14	21.63 ± 1.84*BC*	19.00–24.50	17.89 ± 1.44*	15.84–20.23
		7 Y G2	16	7.30 ± 0.21*AC*	7.00–7.67	1.15 ± 0.03*AC*	1.09–1.18	23.61 ± 1.11*AC*	22.30–25.40	17.89 ± 1.25	16.30–19.88
		8 Y G3	16	8.26 ± 0.16*AB*	8.00–8.50	1.24 ± 0.02*AB*	1.20–1.26	26.15 ± 1.48*AB*	24.50–29.20	17.15 ± 1.17	15.94–19.46
		p-value	–	0.000	–	0.000	–	0.000	–	0.173	–
Total			96	7.32 ± 0.82	6.00–8.50	1.17 ± 0.06	1.01–1.27	23.73 ± 2.47	19.00–29.20	17.45 ± 1.20	15.41–20.23

G1, G2, G3 – primary school grade one, two and three, respectively
CG – control group, EG – experimental group
Analyses were adjusted by sex, age, sex-age and participating groups using the Mann–Whitney *U*-Test and Kruskal–Wallis Test.
A *p* value < 0.05 was considered as statistically significant.
A, B, C – significant difference between different ages (*i.e.*, compared to 6, 7 and 8 years old, resp.)
* significant difference between sexes at the same age

completion, digit span and coding subtests of the WISC-IV scale were analysed in a similar manner.

The Shapiro–Wilk test and the Kolmogorov–Smirnov test (with Lilliefors correction) rejected the normality of all data obtained. A non-parametric statistical analysis was undertaken accordingly, using the SPSS statistical package. To investigate the variation between groups or sexes, the Mann–Whitney *U*-Test was used, whereas the Wilcoxon Signed-Rank Test was employed to test for differences within groups (*e.g.*, to compare the pre- to post-changes). The effect of age was analysed using the Kruskal–Wallis Test (three levels [six, seven and eight years old]). Significant differences between means (pairwise comparisons) were assessed using post-hoc Mann–Whitney *U* tests. Significance was set at $p < 0.05$. All data were summarised with means (*M*) and standard deviations (± *SD*).

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the ethical committee of the Faculty of Physical Therapy, Cairo University, Egypt on 15/7/2018 (approval No.: P.T. REC/012/002010).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

All 96 participants were aged between 6.00 and 8.50 years (*M* = 7.32 years; *SD* = ± 0.82) at intervention time and after excluding the data of the children who withdrew from the study. Overall, the children exhibited a low variation in height (1.01–1.27 m; 1.17 ± 0.06 in average), with greater variability of the measurements of weight (19.00–29.20 kg; *M* = 23.73 ± 2.47) and BMI (15.41–20.23; *M* = 17.45 ± 1.20) (Table 1). No significant differences were found for the effect of sex on the different parameters. In contrast to BMI, height and weight recorded a significant increase with age. In this respect, higher values were recorded at eight years of age compared to the age of six. Regarding sex-age differences, boys and girls alike showed a consistent pattern at the different ages. While the results showed a significant variation in height and weight between the ages of 6, 7 and 8 years for each sex ($p = 0.000$), there were no significant changes recorded on the BMI scores ($p = 0.071$ in boys; $p = 0.173$ in girls). In contrast, boys and girls did not show statistical significance when compared at the same chronological age, except for BMI at six years old. Overall, the paired post-hoc Mann–Whitney *U*-Test analysis between the different possible combinations of age showed a significant variation between children six – seven, six – eight and seven – eight years old for both height and weight with $p < 0.05$. Specifically, there were no significant variations ($p > 0.05$) between the CG and EG in any of the demographic or anthropometric characteristics, and the children in both groups were at the same baseline of motor and cognitive abilities (Table 1).

The BOT™-2 CF diagnostic tool was used to evaluate the four areas of motor development: fine manual control (fine motor precision and integration), manual coordination (manual dexterity and upper-limb coordination), body coordination (bilateral coordination and balance), and strength and agility (running speed and agility, strength). The four relevant subtests of cognitive ability on the WISC-IV scale, including similarities, picture completion, digit span and coding, were used to examine the children's cognitive development.

The results on motor and cognitive competences obtained in this regard refer to the efficiency of the M-i-M *M* program in enhancing a wide range of children's abilities based on receiving 30 minutes a day of moderate-intensity, structured activity. The mean between-group analysis shows that the treated children had significantly higher scores for all motor and cognitive abilities than their peers in the CG (Tables 2 and 3 I). The analysed data from the Mann–Whitney *U*-Test showed a statistical significance in motor abilities between the EG and CG, with *p* at its minimum value (0.000). In this sense, a significant difference was found for the fine motor precision ($U = 203.50$, $Z = 6.10$), fine motor integration ($U = 141.00$, $Z = 7.45$), manual dexterity ($U = 67.50$, $Z = 7.97$), bilateral coordination ($U = 0.00$, $Z = 8.54$), balance ($U = 88.00$, $Z = 7.82$), running speed and agility ($U = 9.00$, $Z = 8.45$), upper-limb coordination ($U = 3.00$, $Z = 8.45$) and strength ($U = 6.00$, $Z = 8.43$) subtests; fine manual control ($U = 88.50$, $Z = 7.81$), manual coordination ($U = 4.50$, $Z = 8.42$), body coordination ($U = 8.00$, $Z = 8.40$) and strength and agility ($U = 16.50$, Z = 8.33) composite areas, and total motor composite ($U = 0.00$, $Z = 8.45$) (Table 2). A very similar pattern of effect was recorded with the similarities ($U = 544.00$, $Z = 4.5050$), digit span ($U = 242.50$, $Z = 6.738$), picture completion ($U = 458.00$, $Z = 5.155$), and coding ($U = 516.00$, $Z = 4.756$) subtests on the WISC-IV for cognitive ability (Table 3 I).

Regarding the effect of sex, the statistical evaluation based on the Mann–Whitney *U*-Test in the EG showed significant differences between boys and girls on the majority of the examined parameters of the BOT™-2 CF. It also appears that the type of MS can influence the sex differences. These findings indicated better performance for boys than girls ($p < 0.05$) in fine motor precision (14.67 ± 2.97 vs. 12.33 ± 2.79, resp.), fine motor integration (15.83 ± 2.33 vs. 13.79 ± 2.62, resp.), fine manual control (50.25 ± 5.62 vs. 45.58 ± 2.28, resp.), body coordination (70.92 ± 2.36 vs. 67.67 ± 3.33, resp.), running speed and agility (14.71 ± 1.60 vs. 13.04 ± 3.01, resp.), strength (26.67 ± 3.97 vs. 22.88 ± 1.48, resp.), strength and agility (63.71 ± 6.13 vs. 56.96 ± 5.30, resp.), and total motor area (68.88 ± 5.97 vs. 63.42 ± 6.01, resp.), with no statistically significant variations ($p > 0.05$) for the manual dexterity, upper limb coordination, manual coordination, bilateral coordination and balance tests (Table 2).

By tracking the sex effect through the different ages (Table 2) the analysis also showed consistent findings between boys and girls for the different ages. A significant difference was found between boys and girls in fine motor precision, fine motor integration, fine manual control, and total motor composite ($p < 0.05$) at age eight. Strength, and strength and agility were significantly varied between both sexes at the different ages. While body coordination was significantly different for the six- and seven-year-olds between boys and girls, running speed and agility only showed a statistical variation at six years old.

However, we found no significant variations between the cognitive profiles of the boys and those of the girls subjected to the intervention program. An exception is picture completion, which was significantly different at $p = 0.041$. Age-based sex analysis exhibited a significant difference between all age groups of boys and girls alike. Paired post-hoc Mann-Whitney U-Test analysis between boys and their peers of girls at the same age level showed a significant main effect for the picture completion subtest ($U = 10.00$, $Z = 2.40$) at the age seven with $p = 0.021$. Except these, no significant differences were observed between the sexes at any of the similar ages (Table 3 I).

Table 2. Between-group differences in children's motor abilities after six months of physical intervention by the Minds-in-Motion *Maze* approach

BOT™-2 CF motor abilities	Participating groups (post-testing) (mean ± *SD*)			Experimental group (post-testing) (mean ± *SD*)														
				Sex effect			Age effect				Sex-age effect							
											Boys				Girls			
	CG	EG	*p*-value	Boys	Girls	*p*-value	6 Y ^{G1}	7 Y ^{G2}	8 Y ^{G3}	*p*-value	6 Y ^{G1}	7 Y ^{G2}	8 Y ^{G3}	*p*-value	6 Y ^{G1}	7 Y ^{G2}	8 Y ^{G3}	*p*-value
1 – Fine motor precision	8.81 ± 1.70	13.50 ± 3.09	0.000	14.67 ± 2.97	12.33 ± 2.79	0.009	11.06 ± 1.73*BC*	14.13 ± 2.85*A*	15.31 ± 2.91*A*	0.000	11.88 ± 2.03*BC*	15.38 ± 2.56*A*	16.75 ± 1.98*A**	0.003	10.25 ± 0.89*BC*	12.88 ± 2.70*A*	13.88 ± 3.09*A**	0.035
2 – Fine motor integration	9.56 ± 1.82	14.81 ± 2.66	0.000	15.83 ± 2.33	13.79 ± 2.62	0.006	13.13 ± 2.58*BC*	15.19 ± 2.66*A*	16.13 ± 1.86*A*	0.011	14.13 ± 2.75*C*	16.25 ± 1.16	17.13 ± 1.89*A**	0.101	12.13 ± 2.10*C*	14.13 ± 3.36	15.13 ± 1.25*A**	0.073
I. Fine manual control	37.10 ± 2.62	47.92 ± 5.89	0.000	50.25 ± 5.62	45.58 ± 5.28	0.007	43.19 ± 4.12*BC*	48.50 ± 5.13*A*	52.06 ± 4.78*A*	0.000	45.13 ± 4.82*BC*	50.63 ± 3.50*AC*	55.00 ± 3.51*AB**	0.002	41.25 ± 2.12*C*	46.38 ± 5.80	49.13 ± 4.12*A**	0.012
3 – Manual dexterity	17.42 ± 3.27	26.29 ± 3.02	0.000	27.00 ± 2.28	25.58 ± 3.51	0.196	24.06 ± 2.98*BC*	26.69 ± 2.41*AC*	28.13 ± 2.19*AB*	0.000	24.75 ± 2.12*BC*	27.63 ± 1.19*A*	28.63 ± 1.41*A*	0.003	23.38 ± 3.66*C*	25.75 ± 3.01	27.63 ± 2.77*A*	0.050
4 – Upper-limb coordination	10.63 ± 1.70	17.15 ± 1.99	0.000	17.46 ± 1.86	16.83 ± 2.08	0.348	16.13 ± 2.06*C*	17.13 ± 1.78	18.19 ± 1.60*A*	0.020	16.50 ± 1.41*C*	17.38 ± 1.69	18.50 ± 2.07*A*	0.073	15.75 ± 2.60	16.88 ± 1.96	17.88 ± 0.99	0.251
II. Manual coordination	47.42 ± 4.92	67.33 ± 5.03	0.000	67.67 ± 4.88	67.00 ± 5.27	0.671	63.00 ± 3.29*BC*	67.13 ± 2.63*AC*	71.88 ± 4.43*AB*	0.000	63.38 ± 3.07*BC*	67.63 ± 2.92*AC*	72.00 ± 4.21*AB*	0.002	62.63 ± 3.66*BC*	66.63 ± 2.39*AC*	71.75 ± 4.92*AB*	0.003
5 – Bilateral coordination	15.79 ± 2.58	23.38 ± 0.73	0.000	23.54 ± 0.66	23.21 ± 0.78	0.220	23.44 ± 0.81	23.13 ± 0.81	23.56 ± 0.51	0.170	23.75 ± 0.71	23.25 ± 0.71	23.63 ± 0.52	0.162	23.13 ± 0.83	23.00 ± 0.93	23.50 ± 0.53	0.479
6 – Balance	14.23 ± 2.74	21.90 ± 2.94	0.000	22.29 ± 2.44	21.5 ± 3.38	0.581	20.00 ± 3.12*BC*	22.50 ± 2.22*A*	23.19 ± 2.54*A*	0.005	21.00 ± 1.31	22.75 ± 2.19	23.13 ± 3.18	0.209	19.00 ± 4.11*C*	22.25 ± 2.38	23.25 ± 1.91*A*	0.041
III. Body Coordination	49.63 ± 6.07	69.26 ± 3.29	0.000	70.92 ± 2.36	67.67 ± 3.33	0.001	67.38 ± 3.74*C*	69.63 ± 2.53	70.88 ± 2.63*A*	0.018	69.75 ± 1.67*	71.00 ± 2.20*	72.00 ± 2.78	0.136	65.00 ± 3.78*C**	68.25 ± 2.12*C**	69.75 ± 2.05*AB*	0.012
7 – Running speed and agility	8.98 ± 1.26	14.71 ± 1.58	0.000	14.71 ± 1.60	13.04 ± 3.01	0.015	12.13 ± 1.86*BC*	14.06 ± 2.08*A*	15.44 ± 2.53*A*	0.001	13.25 ± 1.49*BC**	15.00 ± 1.07*A*	15.88 ± 0.99*A*	0.005	11.00 ± 1.51*C**	13.13 ± 2.47	15.00 ± 3.51*A*	0.071
8 – Strength	17.60 ± 1.69	24.77 ± 3.53	0.000	26.67 ± 3.97	22.88 ± 1.48	0.001	22.50 ± 2.31*BC*	25.19 ± 3.80*A*	26.00 ± 3.74*A*	0.003	23.63 ± 2.83*C**	27.38 ± 4.3*	29.00 ± 2.83*A**	0.021	21.38 ± 0.74*BC**	23.00 ± 1.20*AC**	24.25 ± 0.71*AB**	0.000
IV. Strength and agility	45.38 ± 3.01	60.33 ± 6.62	0.000	63.71 ± 6.13	56.96 ± 5.30	0.001	55.06 ± 4.73*BC*	60.69 ± 6.38*AC*	65.25 ± 4.30*AB*	0.000	57.88 ± 4.94*BC**	65.38 ± 5.45*A**	67.88 ± 2.70*A**	0.004	52.25 ± 2.31*BC**	56.00 ± 2.73*AC**	62.63 ± 4.07*AB**	0.000
Total motor composite	42.65 ± 4.33	66.15 ± 6.54	0.000	68.88 ± 5.97	63.42 ± 6.01	0.004	59.56 ± 3.90*BC*	66.63 ± 4.24*AC*	72.25 ± 3.80*AB*	0.000	62.13 ± 3.44*BC*	69.88 ± 2.80*AC*	74.63 ± 2.56*AB**	0.000	57.00 ± 2.39*BC*	63.38 ± 2.56*AC*	69.88 ± 3.40*AB**	0.000

G1, 2, 3 – primary school grade one, two and three, respectively, CG – control group, EG – experimental group
The analyses between objectively measured MSs and the effect of age, sex and sex-age factors were performed only on the EG data. Statistical analyses were conducted using the Mann–Whitney *U*-Test and Kruskal–Wallis Test.
A p value < 0.05 was considered as statistically significant.
A, B, C – a significant difference between different ages (*i.e.*, compared to 6, 7 and 8 years, resp.)
* significant difference between sexes at the same age

Table 3. Comparison of the cognitive abilities among children after designated period of intervention (six months) by the Minds-in-Motion *Maze* approach. [Between- (I) and within- (II) group analyses]

WISC-IV cognitive abilities	Participating groups (mean ± *SD*)			Experimental group (mean ± *SD*)															
				Sex effect			Age effect				Sex-age effect								
											Boys				Girls				
	CG	EG	*p*-value	Boys	Girls	*p*-value	6 years^{G1}	7 years^{G2}	8 years^{G3}	*p*-value	6 years^{G1}	7 years^{G2}	8 years^{G3}	*p*-value	6 years^{G1}	7 years^{G2}	8 years^{G3}	*p*-value
I. Between-group analysis (post-testing)																			
Similarities	10.46 ± 1.69	12.63 ± 2.38	0.000	12.25 ± 2.46	13.00 ± 2.28	0.247	10.44 ± 1.36*BC*	12.56 ± 1.59*AC*	14.88 ± 1.67*AB*	0.000	10.25 ± 1.49*BC*	11.88 ± 1.55*AC*	14.63 ± 2.00*AB*	0.001	10.63 ± 1.30*BC*	13.25 ± 1.39*AC*	15.13 ± 1.36*AB*	0.000
Digit span	10.27 ± 2.12	13.79 ± 1.88	0.000	13.88 ± 2.09	13.71 ± 1.68	0.958	12.81 ± 1.22*C*	13.25 ± 1.48*C*	15.31 ± 1.89*AB*	0.001	12.75 ± 1.16*C*	13.00 ± 1.20*C*	15.88 ± 2.17*AB*	0.011	12.88 ± 1.36*C*	13.50 ± 1.77	14.75 ± 1.49*A*	0.077
Picture completion	12.46 ± 1.61	14.44 ± 1.74	0.000	14.00 ± 1.69	14.88 ± 1.70	0.041	13.19 ± 1.56*BC*	14.56 ± 1.21*AC*	15.56 ± 1.59*AB*	0.000	12.88 ± 1.46*C*	13.88 ± 0.99*	15.25 ± 1.75*A*	0.019	13.50 ± 1.69*BC*	15.25 ± 1.04*A**	15.88 ± 1.46*A*	0.012
Coding	13.25 ± 1.39	14.98 ± 1.96	0.000	15.33 ± 2.06	14.63 ± 1.84	0.182	13.06 ± 1.57*BC*	15.50 ± 1.21*A*	16.38 ± 1.36*A*	0.000	13.50 ± 1.85*BC*	15.75 ± 1.49*A*	16.75 ± 1.39*A*	0.004	12.63 ± 1.19*BC*	15.25 ± 0.89*A*	16.00 ± 1.31*A*	0.000

WISC-IV cognitive abilities	CG (mean ± *SD*)			EG (mean ± *SD*)			Experimental group (mean ± SD)														
							Boys			Girls			6 years^{G1}			7 years^{G2}			8 years^{G3}		
	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value
II. Within-group analysis																					
Similarities	10.30 ± 1.62	10.49 ± 1.69	0.385	10.27 ± 2.34	12.63 ± 2.38	0.000	9.96 ± 2.44	12.25 ± 2.45	0.000	10.58 ± 2.24	13.00 ± 2.28	0.000	7.94 ± 1.24	10.44 ± 1.36	0.000	10.00 ± 1.21	12.56 ± 1.59	0.000	12.88 ± 1.02	14.88 ± 1.67	0.002
Digit span	10.21 ± 1.80	10.27 ± 2.12	0.786	10.48 ± 1.47	13.79 ± 1.88	0.000	10.29 ± 1.63	13.88 ± 2.09	0.000	10.67 ± 1.31	13.71 ± 1.68	0.000	9.19 ± 0.75	12.81 ± 1.22	0.000	10.44 ± 1.15	13.25 ± 1.48	0.000	11.81 ± 1.11	15.31 ± 1.89	0.001
Picture completion	12.48 ± 1.35	12.46 ± 1.61	0.939	11.75 ± 1.59	14.44 ± 1.74	0.000	11.83 ± 1.66	14.00 ± 1.69	0.000	11.67 ± 1.55	14.88 ± 1.70	0.000	10.56 ± 1.15	13.19 ± 1.56	0.001	11.88 ± 0.96	14.56 ± 1.21	0.000	12.81 ± 1.72	15.56 ± 1.59	0.001
Coding	12.96 ± 1.60	13.25 ± 1.39	0.143	12.63 ± 2.26	14.98 ± 1.96	0.000	12.67 ± 2.08	15.33 ± 2.06	0.000	12.58 ± 2.47	14.63 ± 1.84	0.000	10.88 ± 1.71	13.06 ± 1.57	0.002	12.63 ± 1.71	15.50 ± 1.21	0.001	14.38 ± 1.89	16.38 ± 1.36	0.001

G1, G2, G3 – primary school grade one, two and three, respectively
CG – control group, EG – experimental group
Analyses were conducted between (I) and within (II) groups, and adjusted by sex, age and sex-age effects to explore the potential impacts on the results obtained.
A *p* value < 0.05 was considered as statistically significant
A, B, C – significant difference between different ages (*i.e.*, compared to 6, 7 and 8 years, resp.)
* significant difference between sexes at the same age

Table 4. Within-group differences in children's motor abilities after six months of physical intervention by the Minds-in-Motion *Maze* approach

BOT™-2 CF motor abilities	Participating groups (mean ± *SD*)						Experimental group (mean ± *SD*)														
							Sex effect						Age effect								
	CG			EG			Boys			Girls			6 years[G1]			7 years[G2]			8 years[G3]		
	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value	Pre-test	Post-test	*p*-value
1 – Fine motor precision	8.58 ± 1.93	8.81 ± 1.70	0.443	8.29 ± 2.75	13.50 ± 3.09	0.000	9.63 ± 2.18	14.67 ± 2.97	0.000	6.96 ± 2.65	12.33 ± 2.79	0.000	6.94 ± 2.21	11.06 ± 1.73	0.000	7.81 ± 3.12	14.13 ± 2.85	0.001	10.13 ± 1.82	15.31 ± 2.91	0.000
2 – Fine motor integration	9.94 ± 1.72	9.56 ± 1.82	0.225	9.77 ± 2.25	14.18 ± 2.66	0.000	10.88 ± 1.73	15.83 ± 2.33	0.000	8.67 ± 2.20	13.79 ± 2.62	0.000	8.88 ± 2.25	13.13 ± 2.58	0.001	9.50 ± 1.79	15.19 ± 2.66	0.000	10.94 ± 2.29	16.13 ± 1.86	0.000
I. Fine manual control	37.10 ± 2.56	37.10 ± 2.62	0.971	36.42 ± 5.13	47.92 ± 5.89	0.000	39.21 ± 3.86	50.25 ± 5.62	0.000	33.62 ± 4.75	45.58 ± 5.28	0.000	34.06 ± 4.14	43.19 ± 4.12	0.000	36.00 ± 5.97	48.50 ± 5.13	0.000	39.19 ± 3.92	52.06 ± 4.78	0.000
3 – Manual dexterity	16.83 ± 2.62	17.42 ± 3.27	0.315	16.83 ± 5.80	26.29 ± 3.02	0.000	18.58 ± 4.55	27.00 ± 2.28	0.000	15.08 ± 5.66	25.58 ± 3.51	0.000	12.06 ± 4.48	24.06 ± 2.98	0.000	19.50 ± 3.85	26.69 ± 2.41	0.000	18.94 ± 4.39	28.13 ± 2.19	0.000
4 – Upper-limb coordination	10.08 ± 3.45	10.63 ± 1.70	0.165	10.94 ± 2.38	17.15 ± 1.99	0.000	11.88 ± 1.57	17.46 ± 1.86	0.000	10.00 ± 2.70	16.83 ± 2.08	0.000	8.88 ± 2.25	16.13 ± 2.06	0.000	11.44 ± 1.86	17.13 ± 1.78	0.000	12.50 ± 1.37	18.19 ± 1.60	0.000
II. Manual coordination	45.98 ± 5.65	47.42 ± 4.92	0.116	47.33 ± 7.79	67.33 ± 5.03	0.000	50.67 ± 5.01	67.67 ± 4.88	0.000	44.00 ± 8.71	67.00 ± 5.27	0.000	40.94 ± 7.64	63.00 ± 3.29	0.000	50.00 ± 5.88	67.13 ± 2.63	0.000	51.06 ± 5.60	71.88 ± 4.43	0.000
5 – Bilateral coordination	15.58 ± 3.75	15.79 ± 2.58	0.835	14.31 ± 2.87	23.38 ± 0.73	0.000	16.04 ± 2.68	23.54 ± 0.66	0.000	11.79 ± 2.38	23.81 ± 0.78	0.000	12.81 ± 2.29	23.44 ± 0.81	0.000	14.13 ± 3.44	23.13 ± 0.81	0.000	14.81 ± 3.85	23.56 ± 0.51	0.000
6 – Balance	13.17 ± 2.96	14.23 ± 2.74	0.065	12.25 ± 1.39	21.90 ± 2.94	0.000	11.96 ± 2.10	22.29 ± 2.44	0.000	11.29 ± 1.71	21.50 ± 3.38	0.000	10.69 ± 2.18	20.00 ± 3.12	0.000	12.13 ± 2.01	22.50 ± 2.22	0.000	12.07 ± 1.18	23.19 ± 2.54	0.000
III. Body coordination	48.02 ± 7.64	49.62 ± 6.07	0.312	46.42 ± 6.72	69.29 ± 3.29	0.000	47.04 ± 7.05	70.92 ± 2.36	0.000	40.25 ± 4.07	67.67 ± 3.33	0.000	40.88 ± 4.75	67.38 ± 3.74	0.000	42.81 ± 4.94	69.63 ± 2.53	0.000	47.25 ± 8.29	70.88 ± 2.63	0.000
7 – Running speed and agility	8.92 ± 1.20	8.98 ± 1.26	0.887	9.98 ± 1.98	14.71 ± 1.58	0.000	10.75 ± 1.92	14.71 ± 1.60	0.000	9.21 ± 1.77	13.04 ± 3.01	0.000	8.75 ± 2.02	12.13 ± 1.86	0.001	10.31 ± 2.12	14.06 ± 2.08	0.001	10.88 ± 1.09	15.44 ± 2.53	0.000
8 – Strength	18.21 ± 2.79	17.60 ± 1.69	0.138	17.71 ± 2.76	24.77 ± 3.53	0.000	18.58 ± 2.87	26.67 ± 3.97	0.000	16.83 ± 2.39	22.88 ± 1.48	0.000	16.56 ± 2.99	22.50 ± 2.31	0.001	18.06 ± 2.35	25.19 ± 3.80	0.001	18.50 ± 2.68	26.00 ± 3.74	0.000
IV. Strength and agility	46.00 ± 3.45	45.38 ± 3.01	0.311	46.83 ± 6.60	60.33 ± 6.62	0.000	49.00 ± 8.07	63.71 ± 6.13	0.000	44.67 ± 3.75	56.96 ± 5.30	0.000	44.69 ± 5.56	55.06 ± 4.73	0.000	46.94 ± 9.20	60.69 ± 6.38	0.002	48.88 ± 3.39	65.25 ± 4.30	0.000
Total motor composite	42.25 ± 4.08	42.65 ± 4.33	0.533	41.31 ± 6.27	66.15 ± 6.54	0.000	45.21 ± 5.56	68.88 ± 5.97	0.000	37.42 ± 4.22	63.42 ± 6.01	0.000	38.06 ± 7.17	59.56 ± 3.90	0.000	41.94 ± 6.10	66.63 ± 4.24	0.000	43.94 ± 3.96	72.25 ± 3.80	0.000

G1, G2, G3 – primary school grade one, two and three, respectively
CG – control group, EG – experimental group
The variation within both the control and experimental groups was statistically analysed using the Wilcoxon Signed-Rank Test.
Data of the EG were specifically analysed for the effect of sex (boys and girls) and age (6-, 7- and 8-year-old children) as potential factors for MSs acquisition.
A p value < 0.05 was considered as statistically significant.

Turning to the influence of age (without regard to sex), the results showed that the mean values of the motor (Table 2) and cognitive abilities (Table 3 I) of the children were significantly affected. According to the Kruskal–Wallis Test, the data reported significant variations between the different ages for all MSs. An exception is the bilateral coordination subtest score, which showed insignificant variation across the different ages with $p = 0.170$. Specifically, gains in performance were higher for children aged eight than for those aged six and seven on all BOT^{TM}-2 CF and WISC-IV test scores. Generally, the rate of improvement in MSs and cognitive abilities appeared consistent with ageing.

The paired post-hoc analysis between the different ages showed mixed findings. While an absence of statistically significant variations were observed between the ages of seven and eight years for the fine motor precision, fine motor integration, fine manual control, upper limb coordination, bilateral coordination, balance, body coordination, running speed and agility, and strength motor activities, a highly significant improvement was recorded with the move from age six to seven years in relation to the fine motor precision, fine motor integration, balance, and running speed and agility scores. Remarkable significant differences were calculated between the different age combinations (six vs. seven, six vs. eight, and seven vs. eight) for the manual dexterity, manual coordination, strength and agility, and total motor areas measures (Table 2). On the other hand, the analysed data of cognitive abilities showed significant differences in the similarities and picture completion subtests among all age combinations. A remarkable, significant improvement was also identified for coding between the ages of six and seven and the ages of six and eight years. Meanwhile, 8-year-old children were significantly the best in relation to the digit span scores (Table 3 I). Overall, the highest level of improvement occurred between the ages of six and eight, as the results showed a significant increment in the both motor and cognitive abilities with $p = 0.000$ (Tables 2 and 3 I).

The within-group analysis (Wilcoxon Signed-Rank Test) for the difference between mean scores for both motor and cognitive skills (Tables 3 II and 4) showed significant improvements from pre- to post-test in the EG ($p = 0.000$), but not in the CG. In this context, the mean scores were consistently higher in children in the EG than those in the CG. When the study started, the children in both groups had approximately the same level of motor and cognitive proficiency; no significant variations were observed (data not shown). With regard to the sex effect (EG), it has been shown that boys and girls alike recorded significant positive results ($p = 0.000$) from pre- to post-evaluation in the different measurements of the BOT^{TM}-2 CF and WISC-IV tests. Contrary to the pre-test data, the differences between boys' and girls' motor and cognitive skills decreased after receiving the M-i-M *M* exercises. Without going into excessive detail, the total motor area in boys significantly increased 'on average' from 45.21 ± 5.56 to 68.88 ± 5.97 vs. 37.42 ± 4.22 to 63.42 ± 6.01 in girls with $p = 0.000$.

In view of the WISC-IV standardisation data, the boys showed significant improvement with a difference of 2.29, 3.59, 2.17 and 2.66, from pre- to post-test on the scale score of similarities, digit span, picture completion and coding, respectively, compared to 2.42, 3.04, 3.21 and 2.5 for the girls. Apparently, the rate of improvements in motor abilities was relatively greater than the cognitive abilities for both the boys and girls. Although the improvement in motor abilities was more salient in the boys relative to the girls (Table 4), both sexes achieved approximately the same level of increase with regard to cognitive competence measures (Table 3 I and II).

Post-pre calculated differences in motor and cognitive abilities by age revealed a significant change within each age category: 6-, 7-, and 8-year-old children. The rate of increase was almost congruent for both motor and cognition scores. However, the children in the 8-year-old group recorded the highest rate of increase in relation to the total motor ability (Table 4). Albeit to a lesser extent, the highest improvement in cognitive performance was recorded at the ages of six and seven, particularly for the similarities and digit span subtests (Table 3 II).

Discussion

The current research aimed at measuring motor and cognitive skills among primary school-aged children (six to eight years old) subjected to a vestibular stimulation intervention using the M-i-M *M* program. The main aim was to gain more precise insights into the role of such a PA program in mediating MSs and cognitive competence and their combined associations to the demographic characteristics such as age, sex and sex-age factors.

The current findings provide new information and support some previous research findings, which showed that: (i) vestibular stimulation benefits motor and cognitive development at younger ages; (ii) despite some elements of uncertainty, the developmental trajectory of motor and cognitive skills is closely correlated [39] and display equally protracted developmental timetables of maturation [40]; and (iii) although cognitive competence and MSs may seem related to each other, which skills are related varies across age and sex [41].

The results obtained confirmed the first hypothesis of the study that M-i-M *M*-based PA has the potential to enhance not only MSs, but also cognitive ability among children receiving 30 minutes a day of moderate-intensity structured activity. Analysis the of data focusing on the effect of the M-i-M *M* vestibular stimulation exercise program in promoting the motor abilities of children reflected significant improvements in the EG across all BOT^{TM}-2 CF motor tasks (both fine and gross skills) compared to the untreated control. This was not an unexpected finding as we anticipated this would occur because the M-i-M *M* program was designed to help individuals build good MSs via enhancing balance, coordination, strength and agility [42]. Our results on the rate of motor development of children were generally consistent with previous research that has shown that children engaged in PA on a regular basis had higher scores on BOT^{TM}-2 CF tests [43]. The increased improvement registered here compared to previous studies most likely arises from our use of a mind-body fitness program (namely, M-i-M *M*) to build up the children's abilities. Another reason is the use of a comprehensive, standardised test (*i.e.*, BOT^{TM}-2 CF) for which there is a high degree of internal consistency across the individual sub-tests and when administered across a wide age range; five to 17 years old.

While the EG demonstrated high positive changes from pre- to post-assessment in all motor activities on the BOT^{TM}-2 CF tests, the CG didn't show any significant changes in this regard. The treated children achieved higher mean scores between pre- and post-test of motor abilities. So, as hypothesised, the findings revealed the usefulness of regular vestibular stimulation exercises in increasing motor and coordination skills in this segment of school goers.

The 30-minutes of structured PA intervention implemented in this study supports the growing body of research-based evidence about the importance of structured time [7]. According to the published best practices, the body changes to adapt to the regular exercise. For programs striving to enhance proficiency or to improve a new MS in children, a critical problem is the effects of the amount of practice and the time interval between practice sessions to maintain such abilities [44]. Mitts [32] reported that children consistently involved in M-i-M *M* activities were more motor-efficient compared to their counterparts who did not undergo the training. Vidoni et al. [43] indicated similar findings. This could be explained by the fact that the basis of motor enhancement in children is consistent engagement in activities that require exertion of large and fine muscle groups. In this sense, Ehrlich and Schoppik [45] stated that mature locomotion requires that nervous system to coordinate distinct groups of muscles, even though the pressures that guide the development of this coordination are not well understood.

Apparently, no child in the CG was incentivised (M-i-M *M* practice) to improve their MSs and largely maintained their starting point. From a motor development perspective, improvements in MSs do not occur accidentally through children's growth or maturation, and it is necessary to adapt school/family-based motor learning approaches, considering the ambient environment.

With a prime focus for the M-i-M *M* program on skills-related fitness, health-related fitness, boosting the function of the vestibular system and otherwise, the improvement seen in the treated group is fundamentally underpinned by integrating visual-MSs. Findings from blind infants support this conclusion, as the absence of visual perception from birth seriously affects motor development [46]. Scientific evidence for causation refers to a lack of normal calibration exerted by vision on the proprioceptive and vestibular systems. A well-documented study cited extensive neural connections between the vestibular apparatus and the motor system [47], with primal functions in maintaining balance, posture, and equilibrium by monitoring the motion of the head and stabilising the eyes relative to the environment [45]. To the best of our knowledge, few studies so far have investigated the efficiency of the M-i-M *M* program in enhancing schoolgoers' MSs, whilst a massive amount of research has turned attention to the role of (non-specialised) PAs in eliciting health benefits, notably individuals with developmental disabilities. Lately, fewer studies have been conducted among typically developed children and adolescents with a diversity of intervention modalities and results.

Obviously, fine the manual control, manual coordination, body coordination, and strength and agility motor areas were the motor aspects with the relatively strongest significant improvement from pre- to post-test and when compared between groups (experimental vs. control), due to the rather good response to the related subtests. These results are compatible with some past research that has shown that manual coordination (manual dexterity and upper limb coordination) and the body coordination (bilateral coordination and balance) motor areas interacted strongest under PA interventions [48], in particular with those programs focusing on specific task training in activities of interest, as in our case with the M-i-M *M* program [32, 33]. Specifically, the goal-directed activities of the M-i-M *M* reinforce the coordination and balance aspects that are most related to cognition for more positive outcomes on fundamental MSs in children.

With regard to the cognitive abilities, it is interesting to show that only children who regularly attended the M-i-M *M* vestibular stimulation exercise program attained significant gains in the post-test, when compared with the non-intervention CG. Children engaged daily in the M-i-M *M* activities improved their abilities in the similarities, picture completion, digit span and coding subtests and improved their concentration and attention by the end of the intervention period compared to the beginning of the study. Collectively, these results converge in supporting the promising role of the M-i-M *M* program in strengthening and maintaining cognitive abilities in young children.

The literature contains numerous and conclusive results supporting that vestibular-stimulating PA programs have direct positive impacts on cognition and the ability to deliver real intellectual benefits that provide the base from which children can fully engage in behaviours and interactions that uplift learning. We assume that vestibular-stimulating PA triggers sensory conflicts, which cause appropriate stimulation of the vestibular system, proprioceptors, and the brain's memory/learning centres, leading to an improved relationship between them, which in turn should enhance cognitive functioning. Coordinative exercises involve significant top–down cognitive processing and the ability to ignore automatic behaviours [49]. Additionally, there is evidence supporting the symbiotic association between PA and cognitive functions in children, and it is likely that this synchronisation is causal rather than merely associational [31, 50]. Brain growth in the prefrontal cortical area is thought to be representing the crucial point in this regard [49]. The current findings may find a plausible explanation in the executive function hypothesis. This hypothesis claims that exercise-training sessions cause a significant increase in grey matter volume and greater white matter integrity that is related to prolonged growth of myelination in the prefrontal and frontal cortex [51, 52]. Since these finding suggest that brain functioning is sensitive to an active lifestyle in which PA is a central factor, an essential goal for the M-i-M *M* program is to emphasise the importance of PA to enhance cognitive skills in childhood and prevent sedentary lifestyle.

A core component of the current study was devoted to assessing age- and sex-associated differences in motor and cognitive abilities in children undergoing the intervention (experimental). The data confirmed the feasibility of the study design used regarding this point. The M-i-M M group showed significant variation between boys and girls across most test items of the BOT™-2 CF, but not for cognitive tasks on the WISC-IV scale. In this context, boys outperformed girls across a range of motor tasks (*e.g.*, fine manual precision, fine manual integration, fine manual control, body coordination, running speed and agility, strength, strength and agility, and total composite motor area), and that for specific tasks, including manual dexterity, upper limb coordination, manual coordination, bilateral coordination and balance, no significant variations were observed.

Reviewing the published biomedical literature disclosed vast explorations of the role of sex in the acquisition of skills in school-aged children. Even though our results appear consistent with a large prior body of empirical research, there have been some studies that reported findings pointing in the opposite direction. Regardless of the physical or physiological capacities that could make a difference between boys and girls, variability of results in tests can be attributed to the multiplicity of different assessment tools.

Specifically, boys were more skilful in certain fine (*i.e.*, fine manual control and its related subtests) and gross (*i.e.*, body coordination, strength and agility and its related subtests) MSs. These results coincide with what has been reported that sex differences can strengthen a particular physical/MS [53–55]. In a widely cited investigation, Junaid and Fellowes [56] demonstrated that girls scored significantly higher than boys on visual motor and locomotor tasks, suggesting that girls attain manual dexterity earlier than boys.

However, boys were more skilful in object control and object manipulation skills, including throwing, kicking and catching skills [57]. Another relevant empirical study revealed that sex differences in motor performance during childhood and adolescence were not related to age, but actually to the development of sex differences due to biological and environmental sources [58].

The inclusion of age as a determinant of the influence of sex indicated a similar context in which many aspects of boys' motor functioning significantly surpassed those of girls in the different age groups examined. For instance, at eight years old, boys were more skilful than their same-age female peers in fine manual control and its related subtests. Additionally, boys aged six and seven achieved higher scores in body coordination than their counterparts of girls at the same ages. Sex differences were present in strength, and strength and agility from six to eight years old, with boys having better performance than girls. In this sense, Kokštejn et al. [57] reported that differences between school-age boys and girls in the fundamental gross and fine MSs exist but these differences fluctuated when analysing by age.

Paradoxically, the improvement in cognitive functioning tended to be similar between boys and girls receiving M-i-M *M* intervention activities. Although the boys and girls in the EG attained positive significant results based on post/pre-evaluation, the comparison between them did not show any significant variations over all the examined parameters of similarities, digit span, picture completion, or coding tasks. No significant results were recorded for the same-age peers of boys and girls either. This may contradict the results of some research that confirms that sex differences in intellectual ability exist, and this may be pertinent to prenatal or early postnatal sex hormone exposure [59]. In this context, research referred to the importance of the parental environment and resources as pivotal elements in children's cognitive development. For example, there is a consensus that the early formation of children's cognitive ability is positively related to older, highly educated and high socio-economic status parents [60]. We may argue that the M-i-M *M* activities compensated for the biological and environmental differences between the sexes.

Regarding the effect of age (without considering sex), the present results confirmed that all MSs and cognitive abilities significantly improved with age from six to eight due to the intervention practices. Conflicting results, however, were found between the ages of six to seven and seven to eight. Age-associated differences in coordination-related motor performance, fitness-related motor performance, and total motor performance in children are a subject of extensive explorations in movement intervention studies. Published results confirm that motor competence, including coordination, balance and strength abilities, are improved innately from childhood (6–12 years) to young adulthood (19–25 years), [38, 61] and become stronger through adapting to a PA intervention program. Regardless of the effect of age, the findings on MS or cognition may be inconsistent because of the accompanied environmental conditions or parents' socio-economic backgrounds. Highlighting the difference in opportunities available to children is, therefore, very important.

Remarkably, we found that age was the paramount factor affecting the children's motor and cognitive abilities, followed by sex. Currently, there is renewed interest supported by broad empirical evidence regarding the role of age in motor and cognitive health. Physiologically and according to previously published research results, the age period is crucial for every child to not only refine and improve their MSs but also to enhance their cognitive abilities. That is why understanding the need to invest in young children is so important, to maximise their future well-being. There is a general consensus that younger children face more movement difficulties than older children and react differentially to their environment. Better motor performance is associated with higher ages and develops similarly in boys and girls between six and ten and up to 13 years old [62, 63]. Significant evidence also refers to the superiority of the older ages in achieving higher cognitive-based academic success compared to younger ones [64]. These findings were previously discussed on the grounds of functional brain development and the different rates of cerebral maturation. The promising results obtained on the cognitive abilities of the children in this study may raise earnest questions about the impact on these academic achievements, although this was not a goal of the current study.

The statistical analysis of WISC-IV measures also showed that the children achieved the most significant improvements (with or without sex inclusion) in the period from six to eight years old. The concept that intense PA interventions during early childhood may be the ultimate solution to enhance children's motor and cognitive abilities without considering other supporting factors is shrouded in uncertainty. The current results of the study may agree, to some extent, with the notion of the positive impact of the first year of schooling [65], but the main idea remains that the first three academic years is vital to the potential cognitive and intellectual learning. In fact, many aspects of the intellectual abilities are increasingly improved, reorganised and expanded, especially at the beginning of schooling. Indeed, structured on-site PA programs such as M-i-M *M* during this period can make a vital change in the way of promoting the MSs, which are considered a precursor of cognition and academic performance in children.

Limitations

The results of the current study provide information that may be important in enhancing the motor and cognitive competences of school-aged children. Initially, a number of limitations hindered our ability to begin the studies and to draw the final conclusions. The study experienced temporary difficulties in convincing school officials and parents of the aims of the study, which soon faded away after an information meeting of all concerned parties. Hence, the necessary support was provided for the successful completion of the study by recruiting the purposive sample and allocating sufficient time and an appropriate place.

Conclusions

The present study provides the first systematic insights into the sensory stimulation of the vestibular system using a structured PA program, which can be used to enhance the latent capacities of children early in their school life. Data obtained indicate that the M-i-M *M* intervention achieved significant changes in young students' motor performance, particularly in balance and coordinated-related motor performance. The children also showed real improvement in their cognitive abilities. Even though, the improvement percentage in almost all motor and cognitive abilities from pre- to post-test (data not reported) was in favour of the younger children (six years old), the eight-year-old children statistically attained the best results when compared to their peers of six- or seven-year-old children based on the post-test findings. Specifically, the cognitive development was similar in both boys and girls, with the boys having an apparent advantage over the girls in many aspects of motor behaviours, as affected by the *Maze* practices, which may raise serious questions about the role of age and sex in implementing intervention-based programs. As such, it is imperative to consider sex/age-sensitivity training to minimise expected gaps in results.

In conclusion, future research is needed to repeat the findings of the M-i-M *M* intervention in the context of different settings, different cohorts (typical and atypical school-age children), and with additional instruments to gain a more comprehensive view of the effects on motor and body-management skills as well as the level of performance on cognitive and academic abilities.

Clinical massages

Using a structured PA program to stimulate the vestibular apparatus was associated with noticeable improvements in the physical and mental abilities of children.

The feasibility of the M-i-M *M* program in young school-aged children is warranted, given its importance in shaping or motivating MSs and executive functions early in their academic lives.

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Disclosure statement

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Conflicts of interest

The authors state no conflict of interest.

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