The Journal of Strength and Conditioning Research

A Pedagogical Approach to Integrative Neuromuscular Training to Improve Motor Competence in Children: A Randomized Controlled Trail

Raquel Font-Lladoó,[1] Víctor Ló pez-Ros,[1,2] Alicia M. Montalvo,[3] Graham Sinclair,[1] Anna Prats-Puig,[1] and Azahara Fort-Vanmeerhaeghe[4]

[1]University School of Health and Sport (EUSES), University of Girona, Girona, Spain; [2]Faculty of Education and Psychology, University of Girona, Girona, Spain; [3]College of Health Solutions, Arizona State University, Phoenix, Arizona; and [4]Department of Sports Sciences, FPCEE and FCS Blanquerna, Ramon Llull University, Barcelona, Spain

ABSTRACT

To assess the effectiveness of a pedagogical approach to an integrative neuromuscular training (INT) program as a warm-up in physical education (PE) lessons in healthy children: (a) to improve the level of motor competence (MC) and (b) to master fundamental motor skills (FMS) patterns, considering the baseline MC level and the time spent when performing different motor tasks. One hundred ninety students (7.43±0.32 years; 52% girls) were included in this randomized controlled trail and grouped up according to MC basal levels (L1-L4). Motor competence and FMS patterns (CAMSA protocol) were assessed before and after the intervention in a group-based INT warm-up (n 5 97) and a group-based conventional warm-up (n 5 93). The INT program improved MC ($p<0.001$; $d=0.71$) and FMS ($p<0.001$, $d=0.52$). The independent predictors of MC change were: baseline MC level ($\beta=2196$; $p<0.012$), time spent to perform the task ($\beta= 20.235$ $p<0.003$), and participation in the INT program ($\beta=0.201$; $p<0.005$), explaining 71% of its variability. The INT warm-up shows correlations between improvements in MC in relation to time reduction (L1 $p=0.016$, d, L2 $p=0.001$, and L4 $p=0.001$) and FMS patterns (L1 $p<0.001$, L2 $p<0.003$, L3 $p<0.005$, and L4<0.001) Moreover, only L3, it showed correlation between changes in time and FMS mastery (p 5 0.001). Our results showed that a pedagogical approach to an INT program developed as a warm-up in primary school PE lessons can improve MC and FMS patterns in all subjects, independent of the initial MC level. More interestingly, only in L3, the improvement in MC can be explained by the balance in time required to perform the task and the level of improvement in FMS patterns.

Key Words: fundamental motor skills, time required in task, pedagogical methodology, motor competence level

Introduction

Motor competence (MC) can be described as the sum of capacities, abilities, and types of knowledge that allow the solving of motor problems throughout life (5) and implies the ability to adapt movements to the environment (30). Motor competence is a primary underlying mechanism that promotes engagement in adequate health-related physical fitness and activity in adulthood (34). Intermediate to high levels of MC are required for participation in many physical activities associated with higher levels of performance and health-related physical fitness (34).

Fundamental motor skills (FMS) are elementary units of movement of locomotion, stability, and object control (10,17,31) that allow us to solve motor problems created by different contexts (3). To perform the motor skills involved in several sport and physical activities, accuracy and speed of FMS are necessary (37). It is well known that the development of FMS mainly depends on the biological maturational processes and on the process of learning and acquisition, which at the same time depends on quantity and quality of practice (10,13,17). Several theoretical frameworks of motor development (2,4,10) show that this process of development is not linear, and a window of opportunity for enhancing motor learning exists between 6 and 8 years of age (2,20,29). According to the long-term athlete development model (2), this sensitive period mainly consists of steady-state growth velocity, greater neuroplasticity, conditions, and higher levels of myelin in the nervous system (15).

Several authors (15,19) have suggested that the development and mastery in FMS should be a goal for elementary school children. In this vein, some methodologies and pedagogical approaches exist (1,23). Integrated Neuromuscular Training (INT) is a specific methodology that focuses on the development and mastery of FMS and physical fitness (24–26). Integrated Neuromuscular Training consists of general tasks, including locomotor, stability and object control fundamental skills, and strength and conditioning tasks, including dynamic stability, coordination, strength, plyometrics, speed and agility, and fatigue resistance components (8,9). Integrated Neuromuscular Training initiated in prepuberty and maintained into adolescence is effective in increasing physical activity (PA) participation and intensity in adulthood (8,25). Other studies in prepubertal children have shown an improvement in FMS performance after INT programs (8,9,26). Physical education (PE) lessons in schools are valuable settings to promote the PA and to provide a good opportunity for all children to develop MC and FMS (10,22,23). However, little is known about the effects on FMS patterns and MC of a pedagogical approach to an INT program during warm-up in PE les- sons in prepubertal children, especially in relation to the baseline MC level and the time required to perform the tasks. The idea of using warm-up as a period for the specific practice of basic con- tents is based on the fact that pedagogical research has shown that in PE classes we do not have enough time to work in depth with all contents and that a pedagogical approach to INT can provide the opportunity to achieve some basic physiological and motor developmental goals.

The main purpose of this study was to assess the effectiveness of a pedagogical approach to an INT program as a warm-up in PE lessons in healthy 7 to 8-year-old children: (a) to improve the level of MC and (b) to master FMS patterns, considering the baseline MC level and the time required to perform different motor tasks in a dynamic context.

Methods

Experimental Approach to the Problem

Physical Education, Health, and Children (PEHC) is a randomized control trial research that uses a parallel group design. It was used to explore the impact of an INT program developed as a warm-up in PE lessons, on MC and FMS patterns. The schools were randomly divided into either the control or intervention group. All children were studied preintervention and post-intervention (Table1).

Table 1: Randomized controlled trail design*

	Control (2 schools children)	**Intervention (3 schools children)**
Week 1	Pretest (anthropometric, MC and FMS)	
Week 2-14	Conventional warm-up (20') + PE curricula	INT warm-up (20') + PE curricula
Week 15	Post test (anthropometric, MC and FMS)	

* MC=motor competence; FMS=fundamental motor skills; INT=integrated neuromuscular training; PE=physical education.

Subjects

A total of 281 healthy children were eligible for the study and 204 participated between 2016 and 2017. Subjects were recruited from schools in Cassà de la Selva and Salt, both in northern Spain. The inclusion criterion at baseline was (a) age between 7 and 8 years.

The exclusion criteria were as follows: (a) major congenital abnormalities, (b) evidence of chronic illness or chronic medication use, (c) musculoskeletal or neurological disease, (d) functional limitations, (e) pain or dysfunction in the upper or lower extremities during exercise, and (f) completion of less than 80% of the INT program.

Two hundred and four children were included in the randomized design randomly separated into either the control (n=99, 2 schools) or intervention (n=105, 3 schools). Fourteen subjects dropped out for the following reasons: (a) discontinued intervention, completed ,80% of the INT program (3/14); (b) lost during follow-up (6/14); and (c) were excluded from analysis because of missing data (5/14).

One hundred ninety children were included in the final analysis (90 boys and 100 girls; age, 7.43± 0.32yr) randomly separated into either the control (n=93, 2 schools) or intervention (n=97, 3 schools) (Figure 1).

The Institutional Review Board of Dr. Josep Trueta Hospital approved the research, which confirmed to the recommendations of the Declaration of Helsinki. Informed consent and assent were obtained from subjects and their parents.

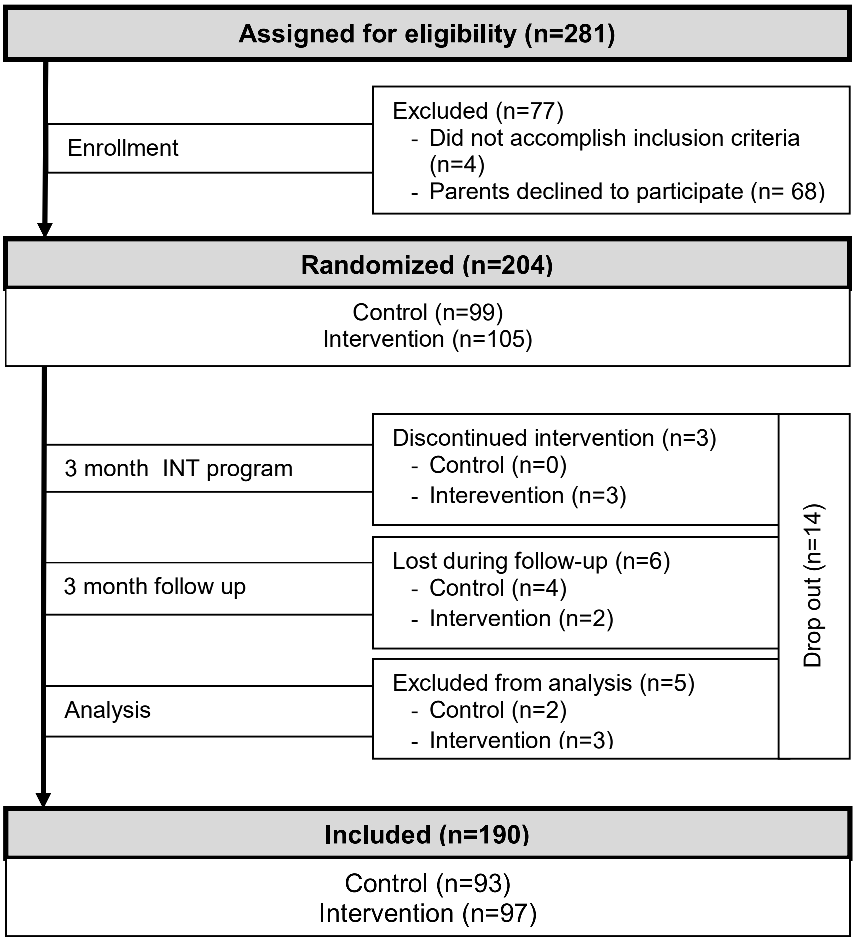

Figure 1: Flowchart of research methodology

Procedure

Preintervention Testing. Anthropometric examinations were performed in the morning. Body mass was measured wearing light clothes with a calibrated scale, and height was measured with a Harpenden stadiometer. The body mass index (BMI) was calculated as body mass divided by the square of height in meters. Age and sex adjusted SD scores for the BMI were calculated using regional normative data. Maturity offset was estimated using the equation created by Mirwald et al. to predict peak height velocity (14,21).

Motor competence and FMS were examined by the Canadian Agility and Movement Skill Assessment (CAMSA) test which measures fundamental, combined, and complex movement skills in a dynamic environment (18), taking into account the time spent. In accordance with the theoretical framework, we assume that the ability to effectively adapt FMS in dynamic and progressively more complex environments, considering the time required to perform the tasks, is evidence of the MC level (18,37). The evaluation of isolated skills does not take into account combined and complex movement capabilities, or reflect the open, dynamic, and complex physical activity environments typical of childhood play and sport (18). In brief, the CAMSA assessment requires children to travel a total distance of 20 m while completing 7 FMS (2-foot jump, sidestep, catch, overhand throw, skip, 1-foot hop, and kick) in as short a time as possible. Each child did 2 practice trials followed by 2 video-recorded measured trials, which were timed while testing. The MC score was calculated, by the video-recorded measured trial, as the sum of the value obtained for each skill (sum 14 CAMSA points) and time scores (14 CAMSA points). Children who were able to accurately combine the speed and skill components of the assessment obtained the highest raw score of MC (18). Fundamental motor skills were analyzed and calculated as previously described by Longmuir (2017), 2-foot jump, overhand throw, skip, 1-foot hop, and kick (max. 2 CAMSA points each), sidestep (max. 3 CAMSA points), and catch (max.1 CAMSA points); the time to perform the task was not considered when FMS were calculated.

To blind the assessment procedure, all video recordings were codified by a researcher and were analyzed by another one. To select the analyzer, 2 investigators made observations on 50 tests, and the results were compared. The analyzer who presented less variability in their analysis was selected. The analyzer was always the same to minimize interobserver variability. The intrasubject coefficient of variation for measurements was found to be less than 6%.

Intervention. A pedagogical approach to an INT program was developed to be applied during warm-up in PE lessons. The INT intervention was administered over 3 months. Subjects trained 20 minutes per day as a regular warm-up in PE lessons, 2 days per week for a total of 24 sessions. The intervention of this study consists of 3 units of training focused on 3 different FMS: loco- motor (see Table, Supplemental Digital Content 1, locomotion_INT tasks progressions with feedback, http://links.lww.com/ JSCR/A217), stability (see Table, Supplemental Digital Content 2, stability_INT tasks progressions with feedback, http://links. lww.com/JSCR/A218), and object control skills (see Table, Supplemental Digital Content 3, object control_INT tasks progressions with feedback, http://links.lww.com/JSCR/A219). Each unit included 8 training sessions: (a) 3 structured gamified sessions, focused firstly on the body control and awareness and then on FMS and physical conditioning components and (b) 5 sessions with circuits of 7 tasks (each subject did 12 repetitions of each circuit with 1 minute of rest between each). In addition, the 5 circuit sessions of each unit were made up of 5 levels of complexity, which included the main components of physical conditioning that characterizes INT (dynamic stability, coordination, strength, plyometrics, speed and agility, and fatigue resistance) (19,24). All sessions were supervised by 2 professionals: (a) the PE teacher previously trained in the INT program in 4 sessions: familiarization with the INT material (1 hour), theoretical frame- work (1 hour), example of the INT program in practice (2 hours), how to give feedback (2 hours); and (b) an INT expert (Sports Science PhD student different to observer and statistics analyzer) to mentor the PE teacher to improve the quality of instructions and feedback.

Postintervention Testing. Postintervention data collection followed the same procedure used for preintervention data collection. All subjects in both groups were invited to participate in postintervention testing.

Statistical Analyses

For the descriptive analysis, we computed the means of absolute and relative frequencies for categorical variables of interest and measures of central tendency and statistical dispersion for numeric variables. Changes of FMS mastery and MC were determined as a subtraction between the final CAMSA points score and the initial CAMSA points score. Changes of time were determined as a subtraction between the time required in the final CAMSA trail and the time required in the initial CAMSA trail. Differences across groups (control vs. intervention) at baseline as well as the increase seen in each variable were analyzed by the independent t test. Mean difference and between-group difference Cohen’s d were calculated for each pairwise group comparison. The Cohen’s d result was qualitatively interpreted as follows: effect size <0.2 as trivial, 0.2–0.49 as small, 0.50–0.79 as medium, and >.0.8 as large. A multiple linear regression analysis was performed to identify predictor variables and significant effects in the change of MC. The dependent variable in the model was the change in MC (considering the level of mastery of FMS and the time required to perform the tasks) before and after the 3-month intervention. The independent variables were as follows: INT program participation, baseline MC, time required to perform the task, age, sex, and maturity offset. The correlations between changes in the MC level, baseline MC level, change in the time, change in FMS, and participating in the INT program was explored using Pearson correlation. The stratification of baseline MC, based on quartiles, was level 1 (L1)=beginning (10 CAMSA points), level 2 (L2)=progressing (10–13 CAMSA points), level 3 (L3)= achieving (13–17 CAMSA points), and level 4 (L4)=excelling (17 CAMSA points). Two-way analysis of variance was used to calculate the significant interaction effect between INT intervention and baseline MC levels on the combined dependent variables. The t test (α=0.05) was used to calculate the MC change, time changes, and changes in the level of mastery of FMS patterns between the control and intervention group in relation to baseline MC levels. The results were calculated as a percentage of the maximum possible score. To analyze the correlations between changes in the MC level, changes in FMS, and changes in time in relation to the initial MC level, the Pearson correlation was used. Statistical analyses were performed using SPSS version 12.0 (SPSS Inc). The significance level was set at $p<0.05$.

Results

Baseline Analysis

Subjects’ baseline characteristics are shown in Table 2. At base- line, no significant differences were observed in most of the studied variables.

Table 2. Subject's baseline characteristics

Measurement	**Control**	**Intervention**	**P**	**d**
N	93	97	--	------
Age (y)	7.39 (.38)	7.47 (0.27)	.18	0.24
Sex (%;F)	0.48; 45	0.57;55	.20	0.18
Maturity offset (y)	-3.48 (0.76)	-3.36 (0.72)	.27	0.16
Motor Competence level (Level†)	2.66 (0.98)	2.49 (4.36)	.29	0.16
Motor Competence (CAMSA* points)	14.35 (4.17)	13.70 (6.54)	.29	0.15
Fundamental Motor Skills (CAMSA points‡)	7.9 (2.30)	7.58 (2.73)	.35	0.12
Time§ (seconds)	21.75 (3.77)	22.03 (3.32)	.59	0.07

*CAMSA: 5 Canadian Agility and Movement Skill Assessment.
Level†: quartile based on MC (L1, L2, L3, and L4).
CAMSA points‡5 Maximum 14 points in 7 skills: 2-food jumping (2p), sliding (3p), catch (1p), throw (2p), skip (2p) 1-foot Hop (2p), Kick (2p).
Time§ (s): time required to perform the task (CAMSA test).
Mean 6 SD. p value from the t test. Examined by the t test.

Analyses of Integrated Neuromuscular Training Results

The INT program showed higher MC results, with a medium ES (6.8% higher than the control, p<0.001; d=0.71), when compared with the control group; the same had been observed in FMS results (13.4% higher than the control with the medium ES p<0.001, d=0.52). Comparing both groups, no significant differences were observed in time spent to perform the assessment tasks (Table 3).

Table 3: Change in Motor Competence and Fundamental Motor Skills between control and intervention groups

Motor skills	**Control**	**Intervention**	**p**	**d**
Δ Motor competence (CAMSA MC score)	1.96±2.32 (6.8%)	3.75±2.62 (13.57%)	**< .0001**	0.71
Δ Time (s)	21.7±2.7 (12.14%)	21.57±2.12 (11.21%)	<0.507	0.05
Δ Fundamental Motor Skills (CAMSA points)	0.65±4.6 (4.6%)	2.52±2.26 (18%)	**<.0001**	0.52

*Δ motor competence 5 change in motor competence; Δ time 5 change in time required to perform the task (CAMSA test), Δ fundamental motor skills included in the CAMSA test 2-foot jump, slide, catch, throw, skip, 1-foot hop, and kick. Mean 6 SD. p value from the t test. Percentage (individual CAMSA points/protocol CAMSA points). Examined by the T test..

In multiple linear regression analysis, the baseline MC level (β=-0.196; p<0.012), the time required to perform the baseline test (β=-0.235; p<0.003), and participation in the INT program (β=201; p<0.0005), were independent predictors of MC improve- ment, explaining 71% of its variability (Table 4).

Table 4: Change of Motor Competence as dependent variable.

		β	**p**	**R² corrected**
Δ MC level	Baseline MC (CAMSA points)	-0.196	**<.0012**	0.71
	Δ Time (seconds)	-0.235	**<.0003**	
	INT program participation	0.201	**<.0005**	

*Δ MC level 5 change in the motor competence level. Baseline MC 5 initial MC (CAMSA points); Time (s) 5 change in the time required to perform the task (CAMSA test); INT 5 integrative neuromuscular training; Predictor variables to the MC change were examined by ANOVA. Nonexplaining variables 5 age, sex, and maturity offset. Examined by 1-way ANOVA.

After the INT program, changes in the MC level correlate negatively with the baseline MC level (-0.434; p<0.001) and the time required to perform the task (-0.508; p<0.001) and correlates positively with changes in FMS patterns (0.769; p<0.001) and participation in the INT program (0.339; p<0.001). Integrated neuromuscular training intervention, regardless of the baseline MC level, correlates significantly with the MC level and FMS changes (0.421; p<0.001) but not in time invested to perform the task (Table 5).

Table 5: Pearson's correlations between Basline MC level, Change in time, Change in FMS and TNI intervention

	Δ MC level		**Baseline MC level**		**Δ time**		**Δ FMS**	
		p		p		p		p
Basline MC level	-.434	**<.0001**						
Δ time	-.508	**<.0001**	.410	**<.0001**				
Δ FMS	.769	**<.0001**	-.336	**<.0001**	.074	.314		
TNI intervention	.339	**<.0001**	-.077	.293	.039	.597	.421	**<.0001**

*FMS5fundamental motor skills. Baseline MC level5initial motor competence (CAMSA points); Δ Time (s) 5 change in the time required to perform the task (CAMSA test); Δ FMS (CAMSA points) change in fundamental motor skils; INT intervention 5 Integrative neuromuscular training; intervention. Δ MC level 5 change in the motor competence level.

Stratification of the Subjects according to Baseline Motor Competence Levels

There was a statistically significant interaction effect between INT intervention and baseline MC level on the combined dependent variables, F (9, 435.8) = 3.94; p<0.001; Wilks'=0.827 (data not shown).

Children with lower levels of MC at baseline improve more than children with higher MC levels at baseline (L1 [15.61%], L2 [13.34%], L3 [10.85%], L4 [5.98%]). Comparing the intervention group and the control group, L3 is the baseline MC level in which the intervention group improves more (11.5% p<0.0001, d=1.93), the second is L2 (6% p=0.034, d=0.65), and L4 (3.79% p<0.046, d=0.49) is the intervention group which improves least (Table 6).

Table 6: Increment of Motor Competence level, time spent in task and FMS with the categorized baseline Motor Competence level

Baseline MC Level		**CONTROL**	**INTERVENTION**	**Increment**	**p**	**d**
L1 Beginning	Δ MC level	4±2.4 14,28%	4.6±3.4 16.42%	2.14%	0.623	0.20
	Δ time	-5.41±3.7 38,64%	-2.59±2.45 18.5%	**20.14%**	**0.005**	0.90
	Δ FMS	1.2±1.31 8.57%	3.5±2.87 25%	**16.43%**	**0.008**	1.03
L2 Progressing	Δ MC level	2.95±2.27 10.54%	4.52±2.52 16.14%	**6%**	**0.034**	0.65
	Δ time	-3.18±2.83 22.71%	-1.12±1.99 8%	**14.71%**	**0.011**	0.84
	Δ FMS	.54±1.68 3.86%	3.39±2.21 24.21%	**20.35%**	**<0.000**	1.45
L3 Achieving	Δ MC level	1.44±1.73 5.1%	4.6±1.59 16.6%	**11.5%**	**<0.000**	1.93
	Δ time	-.44±1.44 3.24%	-2.37±1.61 16.93%	**13.69%**	**<0.000**	1.26
	Δ FMS	0.81±.16 5.81%	2.57±1.39 18.35%	**12.54%**	**<0.000**	1.78
L4 Excelling	Δ MC level	1.14 ±2.23 (4.09%	2.20±2.05 7.88%	**3.79%**	**0.046**	0.49
	Δ time	-0.78±1.58 5.57%	-0.75±1.33 5.36%	0.19%	0.940	0.02
	Δ FMS	0.41±2.00 2.93%	1.3±1.9 9.29%	**6.36%**	**0.045**	0.52

Δ MC level. Change in motor competence level.
Δ Time: Change in time required to perform the task (CAMSA test).
Δ FMS. Change in Fundamental Motor Skils included in CAMSA test two foot jump, slide, catch, throw, skipping, 1 food jump, kick).
Mean (SD). Percentage (individual CAMSA points/protocol CAMSA points). P value from T-test.)
Increment = Δ MC level intervention group - Δ MC level control group
Examinated by T-student

*Δ MC level5change in the motor competence level; Δ time 5 change in the time required to perform the task (CAMSA test); Δ FMS5 change in fundamental motor skills included in the CAMSA test 2-foot jump, slide, catch, throw, skip, 1-foot hop, and kick; Mean 6SD (percentage) (individual CAMSA points/protocol CAMSA points).
Change=Δ MC level intervention group- Δ MC level control group.
L1 (10, 18): Level 1 (N control group, N intervention group).
Examined by the T test. p value from the T test.

The time required to perform the task improved significantly in L1 (20.14%, p=0.005, d=0.90) and L2 (14.71%, p=0.011, d=0.84) in the control group, but in L3, the time required to perform the task improved significantly (13.69%, p<0.000, d=1.26) in the intervention group. At level 4, the time improvement was not significant. Fundamental motor skills improve in all baseline FMS levels, but the intervention group improved more than the control group, especially in the lowest levels L1 (16.43%; p=0.008), L2 (20.35%; p<0.0001, d=1.45), L3 (12.54%; p<0.0001, d=1.78), and L4 (6.36%; p<0.045, d=0.72) (Table 6).

Regarding the level of correlations, the intervention group shows positive correlations between changes in the MC level and reduced time required (L1 [20.488; p=0.016], L2 [20.669; p<0.001], and L4 [20.412, p=0.015]) and changes in the MC level with changes in the FMS score (L1 [0.921; p<0.0.001], L2 [0.567; p<0.003], L3 [0.592; p<0.005], and L4 [0.631; p<0.001]). But only in L3 (0.672, p=0.001), can a positive correlation between reduced time required and changes in FMS score be observed (Table 7).

Taula 7: Correlations between improvement of Motor Competence, time and fundamental motor skills point

		CONTROL		**INTERVENCIÓ**	
			p		P
L1 (10,18) Beginning	Δ MC level - Δ time	-0.470	0.105	**-0.488**	**0.016**
	Δ MC level - Δ FMS	0.271	0.370	**0.921**	**0.000**
	Δ time - Δ FMS	0.417	0.156	-0.153	0.475
L2 (22,23) Progressing	Δ MC level - Δ time	**-0.649**	**0.000**	**-0.669**	**0.000**
	Δ MC level - Δ FMS	**0.597**	**0.001**	**0.567**	**0.003**
	Δ time - Δ FMS	0.171	0.393	0.567	0.314
L3 (27,21) Achieving	Δ MC level - Δ time	-0.296	0.100	-0.150	0.516
	Δ MC level - Δ FMS	**0.731**	**0.000**	**0.592**	**0.005**
	Δ time - Δ FMS	**0.377**	**0.034**	**0.672**	**0.001**
L4 (34,34) Excelling	Δ MC level - Δ time	-0.392	0.079	**-0.665**	**0.001**
	Δ MC level - Δ FMS	**0.768**	**0.000**	**0.631**	**0.000**
	Δ time - Δ FMS	0.269	0.257	0.096	0.647

*Δ MC level 5 change in the motor competence level; Δ time 5 change in the time required to perform the task (CAMSA test); Δ FMS5change in fundamental motor skills included in the CAMSA test 2 foot jump, slide, catch, throw, skip, 1-foot hop, and kick)L1 (10, 18): level 1 (N control group, N intervention group).
Examined by Pearson Correlation.

Discussion

As far as we know, the current study (PEHC) is the first to show improvements in MC and FMS patterns, using an INT pedagogical approach as a warm-up in PE lessons in primary schools regarding the baseline MC level and the time required to perform the task.

After training in the pedagogical approach to INT, the change in the MC score and FMS patterns (locomotor and stability skills and object control skills) increased significantly in the intervention group compared with the control group. Several authors suggest that a critical "window of opportunity" exists during the developmental years (7–8 years old) within which children are more sensitive to training-induced adaptation (2,4,10,16). As suggested above, this period involves steady-state growth velocity, as well as increased neuroplasticity conditions and levels of myelin in the nervous system (20,36). This could explain the significant improvement in MC and FMS in 7–8 years' children, especially in the intervention group but also in the control group because both groups had general curricular PE lessons (28) during the intervention.

In this study, 3 different variables, baseline MC level, time required to perform the task, and participation in the INT pro- gram, can explain changes in MC.

First, the baseline MC level shows a large intersubject variability, from the beginning to the excelling level. By 7–8 years, children should be at a mature stage of motor development in some FMS (4,10). However, it is important to take into account that MC and FMS mastery also depend on the quantity and quality of motor experiences of each child (10).

To stimulate a rich quantity and quality of motor experiences, the pedagogical approach of the INT program is mainly based on a constraints-led perspective (6,27). It is designed to consider open tasks (37) and sequenced complexity constraints applied to a specific unit task and environment (6,27).

The INT program benefits all subjects independently of their baseline MC levels, but more significant improvements can be observed in children with middle levels at baseline (4): L2 (progressing) and L3 (achieving) in our study. It is known that motor development is not a linear process, regressions and advances take place. However, when a FMS pattern is acquired, a steady-state exists where learners gain confidence (32). Motor competence improvement also depends on the adaptability of FMS to velocity (37). Here confidence in FMS patterns is necessary, and consequently, an exponential improvement in MC can be observed (11). Our study shows that subjects at L3 (achieving) are the most sensitive to the intervention suggesting that this steady-state appears at this level of mastery. This is not the case in L4 (excelling), where FMS patterns have been assimilated and INT intervention did not specifically train velocity as in highly competitive situations (37).

Second, time to perform the task is determinant for the MC level. Motor competence depends on efficacy (related to achieving the goal) and efficiency (related to energy expenditure in task) (17). Fitts' and Posner (28) law (1954) indicates that if an individual want to achieve accuracy, he or she needs to slow actions down. In this way, it is important to consider that in the first stage of FMS acquisition, the quality of motor response is negatively affected by the speed (11,37). So, in our study, the biggest improvement in MC and FMS can be seen in children with middle baseline MC levels because they improve the quality of FMS patterns although they required more time completing the circuit.

These results can be explained because the INT intervention program puts the emphasis on the FMS pattern mastery rather than on the time required to do the task. Integrated neuromuscular training intervention did not specifically train velocity (37). Considering the previous, in middle levels, especially in L3, the greater MC improvement depends to the balance between the level of the FMS pattern, and time spends in the task (18).

Finally, participation in the INT program offers an opportunity to improve mastery of MC and FMS patterns. The INT program is mainly structured in accordance with Gallahues' FMS organization (10), and uses several tools such as the Photo Game, motor skills and physical conditioning circuits, and motor skills and physical conditioning games. The Photo Game is used to improve body control and awareness, developing understanding of the placement of body parts in static patterns (11,12). A PE teacher guides this scaffolding process, maintaining an explicit dialogue with students. This type of instructional intervention allows the sharing of concepts and meanings and facilitates learning through feedback (38). The INT program also proposes 5 sessions per unit (second, third, fourth, sixth, and seventh) in motor skills and physical conditioning circuits. According to schema theory (32,33), the circuits of each unit are focused on the same general motor programs. However, the specific forms of each FMS execution are modified in each circuit by different constraints, affecting different parameters of motor schemas (32,33,35,38). At the same time, the circuits developed physical conditioning capacities underlying the FMS, especially strength and agility (9). Finally, the INT program includes 2 sessions (fifth and eighth), where motor skills and physical conditioning are integrated in games. The INT program uses games to facilitate the adaptability of FMS in dynamic environments, considered as complex systems of interrelated constraints.

Mastery and individualized feedback is one of the keys of motor learning in PE lessons (22,23). The INT program includes a model of each exercise and provides kinematic feedback for each FMS pattern. Kinematic feedback, or knowledge of performance (KP), refers to information provided by the teacher, indicating the quality of the student's FMS patterns. Knowledge of performance is a type of intrinsic feedback which guides the learner's attention to a more appropriate focus (39). Learners at the beginner level depend partially on teachers' feedback to detect and correct their errors (6,11,32).

Regarding the main features of the CAMSA protocol, and comparing it with other assessment tools, we highlight that CAMSA includes the measure of the time required to perform the motor tasks. According to our results, time is a key element in the development of MC levels and in the process of mastery in FMS with children (7–8 years old) (11,37).

In conclusion, the implementation of a pedagogical approach in INT programs in PE lessons as a warm-up could be a useful tool to improve MC and FMS patterns in prepubertal children (7–8 years old) at primary schools. An INT program can improve FMS patterns in all children, independent of the baseline MC level. However, MC especially improves in those with middle baseline MC levels because of the balance in time required to perform the task and improvement in FMS patterns, which is possible when confidence with the execution of the FMS pattern exists.

The results of the current study should be considered in light of 2 limitations. First, the duration of the intervention program was limited to 3 months. Second, we have not considered the influences of other physical activities or sports that children may have practiced out of school during the intervention, although the 2 groups are similar.

Practical Applications

The findings of this study provide new knowledge to redesign contents and methodologies to PE lessons to accomplish the goal to improve MC levels and FMS patterns in 7–8-year old children during primary school.

Thus, these findings suggest some relevant considerations for the implementation a pedagogical approach of INT pro- grams in this context: development of INT as a warm-up in PE lessons, specific training of PE teachers in INT, consider the initial MC level to adjust constraints in the design of the INT program focusing on FMS patterns, and specific, individualized kinematic learner feedback. The structure of the INT program proposes the progressive introduction of tasks related to body control and awareness, the generalized motor program and contextualized FMS. At the same time, at the highest levels, it seems important to introduce the velocity as in highly competitive situations to perform tasks. This element is crucial to improve MC required for successful participation in many sports and physical activities associated with higher levels of performance and health-related physical fitness.

Additional work is needed to determine which components of a pedagogical approach to INT offer the greatest potential for MC and FMS development in relation to children's growth and maturation.

Acknowledgments

The authors are grateful to all the children and parents who took part in the study and to EUSES-UdG for the funding to perform the project.

Supported by the University School of Health and Sport (EUSES), University of Girona, Girona, Spain.

R. Font-Lladó conceptualized and designed the study and the intervention, coordinated and supervised data collection, drafted the initial article, and reviewed and revised the article. V. López-Ros critically reviewed the article for important intellectual content. A.M. Montalvo reviewed and revised the article. G. Sinclair reviewed and revised the article. A. Prats-Puig conceptualized and designed the study, designed the data collection instruments, collected data, performed the initial analyses, and reviewed and revised the article. A. Fort-Vanmerhghe conceptualized and designed the intervention, collected data, and critically reviewed the article for important intellectual content.

All authors approved the final article as submitted and agree to be accountable for all aspects of the work.

References

1. Allison PC, Barret KR. Connecting what you teach to why you teach it. In: Constructing Children's Physical Education Experiences. Understanding the Content for Teaching. Boston, MA: Allyn, 2000. pp. 13–81.
2. Balyi I, Hamilton A. Long-term athlete development: Trainability in childhood and adolescence. In: Windows of Opportunity. Optimal Trainability. Victoria, United Kingdom: National Coaching Institute British Columbia & Advanced Training and Performance Ltd, 2004. pp. 194.
3. Barnett LM, van Beurden E, Morgan PJ, Brooks LO, Beard JR. Childhood motor skill proficiency as a predictor of adolescent physical activity. J Adolescheal 44: 252–259,

2009.

4. Clark JE, Metcalfe JS. The mountain of motor development: A metaphor. In. Motor Development: Research and Reviews. Vol 2. Clark JE and Humphrey JH, eds. Reston, VA: NASPE Publications, 2002. pp. 163–190.
5. Connolly K, Bruner JS. Competence: Its nature and nuture. In: The Growth of Competence. London: Academic Press, 1973. pp. 3–7.
6. Davids K, Button C, Bennett S. Traditional theories of skill acquisition. In: Dynamics of Skill Acquisition. Champaign, IL: Human Kinetics, 2008. pp. 3–29.
7. Fitts PM, Posner MI. Speed versus accuracy. In: Human Performance. Belmont, CA: Brooks/Cole Pub. Co, 1967. pp. 109–112.
8. Fort-Vanmeerhaeghe A, Román-Viñas B, Font-Lladó R. Why is it important to develop motor competence in child34hood and adolescence? The basis for a healthy lifestyle. Apunts Medicina de l'Esport 103–112, 2017.
9. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, Kushner A, Myer GD. Integrative neuromuscular training in youth athletes. Part II: Strategies to prevent injuries and improve performance. Strength Cond J 38: 9–27, 2016.
10. Gallahue D, Ozmun J, Goodway J. Motor development: Theoretical models. In: Understanding Motor Development: Infants, Children, adolescents, adults (8th ed.). New York, NY: McGraw-Hill, 2012. pp. 46–62.
11. Gentile AM. Skill acquisition: Action, movement, and neuromotor processes. In. Carr JH and Shepard RB, eds. Movement Science: Foundations for Physical Therapy (2nd ed.). Rockville, MD: Aspen, 2000. pp. 111–187.
12. Haibach P, Reid G, Collier D. Infant motor development. In: Motor Learning and Development. Champaign, IL: Human Kinetics, 2018. pp. 98–114.
13. Haywood K. Theoretical perspectives in motor development. In: Life Span Motor Development (7th ed.). Champaign, IL: Human Kinetics, 2019. pp. 17–27.
14. Kozieł SM, Malina RM. Modified maturity offset prediction equations: Validation in independent longitudinal samples of boys and girls. Sports Med 48: 221–236, 2017.
15. Lander N, Eather N, Morgan PJ, Salmon J, Barnett LM. Characteristics of teacher training in school-based physical education interventions to improve fundamental movement skills and/or physical activity: A systematic review. Sports Med 47: 135–161, 2016.
16. Lloyd R, Oliver J. The youth physical development model: A new approach to long-term athletic development. Strength Cond J 34: 61–72, 2012.
17. Logan SW, Ross SM, Chee K, Stodden DF, Robinson L. Fundamental motor skills: A systematic review of terminology. J Sports Sci 36: 781–796, 2017.
18. Longmuir PE, Boyer C, Lloyd M, et al. Canadian Agility and Movement Skill Assessment (CAMSA): Validity, objectivity, and reliability evidence for children 8-12 years of age. J Sport Health Sci 6: 231–240, 2017.
19. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents. Review of associated health benefits. Sports Med 40:

1019–1035, 2010.

20. Malina RM, Bouchard C. Motor development. In: Growth, Maturation, and Physical Activity (2nd ed.). Champaign, IL: Human Kinetic Pub; 2004. pp. 195–214.
21. Malina RM, Rogol AD, Cumming SP, et al. Biological maturation of youth athletes: Assessment and implications. Br J Sports Med 49: 852–859, 2015.
22. McKenzie TL, Lounsbery M. Physical education teacher effectiveness in a public health context. Res Q Exerc Sport 84: 419–430, 2013.
23. Morgan PJ, Barnett LM, Cliff DP, et al. Fundamental movement skill interventions in youth: A systematic review and meta-analysis. Pediatrics 132: e1361–e1383, 2013.
24. Myer GD, Faigenbaum AD, Chu DA, et al. Integrative training for children and adolescents: Techniques and practices for reducing sports- related injuries and enhancing athletic performance. Phys Sports Med 39: 74–84, 2011.
25. Myer GD, Faigenbaum AD, Ford KR, et al. When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance health in youth? Cur Sports Med Rep: 157–166, 2011.
26. Myer GD, Lloyd RS, Brent JL. How young is too young to start training? ACS Ms Heal Fit J 17: 14–23, 2013.
27. Newell KM. Constraints on the development of coordination revisited. J Sport Exerc Psychol 22s2, 2000.
28. Physical education curriculum for secondary school. Decree 187/2015. Generalitat de Catalunya Official Report. 6945. pp. 245–259.
29. Platvoet S, Faber IR, de Niet M, et al. Development of a tool to assess fundamental movement skills in applied settings. Front Educ 3: 75, 2018.
30. Robinson LE, Stodden DF, Barnett LM, et al. Motor competence and its effect on positive developmental trajectories of health. Sports Med 45: 1273–1284, 2015.
31. Rudd JR, Barnett LM, Butson ML, et al. Fundamental movement skills are more than run, throw and catch: The role of stability skills. PLoS One 10: 10, 2015.
32. Schmidt RA, Lee TD. Motor programs. Motor control and brief actions. In: Motor Learning and Performance. From Principles to Application (5th ed.). Champaign, IL: Human Kinetics, 2014. pp. 89–123.
33. Schmidt RA. Motor Schema theory after 27 years: Reflections and implications for a new theory. Res Q ExercSport 74: 366–375, 2003.
34. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. Quest 60: 290–306, 2008.
35. Turvey MT, Fitch HL, Tuller B. The Bernstein perspective: The problems of degrees of freedom and context conditioned variability. In. Kelso JAS, ed. Human Motor Behavior: An Introduction. Hillsdale, NJ: Erlbaum, 1982. pp. 239–252.
36. Viru A, Loko J, Harro M, et al. Critical periods in the development of performance capacity during childhood and adolescence. Eur J Phys Educ 4: 75–119, 1999.
37. Wang J. Key principles of open motor-skill training for peak performance. JOPERD 87:

8–15, 2016.

38. Wulf G, Schith RA. Feedback-induced variability and the learning of generalized motor programs. J Mot Behav 26: 348–361, 1994.
39. Wulf G. Internal versus external focus feedback. In: Attention and Motor Learning. Champaign, IL: Human Kinetics, 2007. pp. 83–106.