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ORIGINAL

ASSOCIATION BETWEEN EXECUTIVE FUNCTION, INTELLECTUAL MATURITY AND PHYSICAL FITNESS IN PRESCHOOLCHILDREN

ASOCIACIÓN ENTRE FUNCIÓN EJECUTIVA, MADUREZ INTELLECTUAL Y CONDICIÓN FÍSICA EN NIÑOS PREESCOLARES

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ABSTRACT

The main aim of this study is to understand the evolutionary profile of the executive function (EF) and the intellectual maturity (IM) in relation to the physical-motor condition in preschool children. A group of 81 children, 3-6 years old, participated in the project (44 boys and 37 girls). Regarding the testing protocol, tests for assessing physical fitness were included (i.e., strength,

balance, speed, resistance and reaction time). The EF and the IM were analyzed with the Porteus Maze test and the Goodenough test, respectively. The results showed an age effect on both cognitive variables and physical fitness, with significant differences between those variables between age groups. Additionally, the regression analysis reported a significant association between physical fitness (i.e., sprint, handgrip strength and reaction time) and the FE and the MI. In summary, the results obtained suggest a parallelism between the EF and IM with the development of physical fitness.

PALABRAS CLAVE: Physical condition, executive function, intellectual maturity, children, preschool.

RESUMEN

El objetivo principal de este estudio fue conocer el perfil evolutivo de la función ejecutiva (FE) y la madurez intelectual (MI) en relación con la condición físico-motora en niños preescolares. Han participado 81 niños, de edades comprendidas entre 3 a 6 años, 44 niños y 37 niñas. Se realizaron pruebas de condición física de fuerza, equilibrio, velocidad, resistencia y tiempo de reacción. Se analizó las FE y la MI con los test de Laberintos de Porteus y el test de Goodenough respectivamente. En la evolución de las variables cognitivas y de condición física según la edad de los niños, se observan diferencias significativas entre los grupos de edad. La velocidad de desplazamiento junto con la dinamometría manual y el tiempo de reacción son variables que se asocian a las FE y a la MI. Por tanto, existe un paralelismo evolutivo entre el desarrollo de la FE y MI con el desarrollo de la condición física.

PALABRAS CLAVE: Condición física, función ejecutiva, madurez intelectual, niños, preescolares.

INTRODUCTION

The study of child development has gained importance in recent years. The neuroscience of development shows how the first biological and psychosocial experiences affect the development of the brain (Walker et al., 2011). However, the influence of physical activity and physical fitness (PF) in child development is still addressed scant in scientific research. In the childhood, the ability to perform motor acts is an important indicator of cognitive functioning (Field, 2010). Thus, motor and cognitive development in childhood are related to each other (Poranen-Clark et al., 2015). In fact, architectural and functional properties of the brain are closely related to locomotor skills during development (Mierau et al., 2015; Isorna, Rial, Felpeto and Rodríguez, 2005).

Mental and motor events share the same neural substrate, the neuromotor system, or what has been called the psychomotor system. Psychomotor theory emphasizes the leadership role of the motor system in the appearance of

mental events (Tan, 2007). Studies with neuroimaging demonstrate the global link between motor and cognitive performance, which indicates that cognitive and motor skills share neural mechanisms and take advantage of common resources (Stöckel and Hughes, 2015).

The PF is an important biomarker of health from an early age with physical exercise being one of the main determinants of PF (Ortega, Ruiz, Castillo and Sjöström, 2008). Also, there is a significant connection between the growth of the body with PF (Ortega et al., 2011; Travill, 2011) and with cognition (Heinonen et al., 2008), in turn, a causal relationship between PF and brain vitality is highlighted, this link being important when the effects of physical exercise practice are evaluated with cognitive tests associated with executive function (EF) (Tompsonski, Davis, Miller and Naglieri, 2008). The term EF refers to a multidimensional construct that encompasses a series of cognitive processes necessary to perform complex tasks directed towards an objective (Filippetti, 2011). The development of EF during the preschool period can be analyzed through a unitary integrating framework of partial components such as: memory work, inhibition and mental flexibility or change (Miyake, 2000). From 3 to 5 years there is an important development of EF associated with the prefrontal cortex (Garon, Bryson and Smith, 2008).

Children with better PF have a higher cortical activation and cognitive performance (Tompsonski et al. 2008). Chang, Labban, Gapin and Etnier (2012) showed that PF was a significant moderator in the association between physical activity and cognitive performance. Chaddock, Pontifex, Hillman and Kramer (2011) they also point out the importance of physical activity and aerobic fitness for brain health and cognition during development.

Therefore, the evaluation of PF in preschool children should be an essential element for the control and monitoring of the quality of life related to health, with all its health implications, but also, it should be an important action for the follow-up of a healthy motor development and that other authors have associated with a parallel cognitive development (Aberg et al., 2009; Haapala et al., 2013). The first years of life are fundamental for physical, cognitive, motor growth and socio-emotional development, but the magnitude of the relationship between these processes remains unclear (Sudfeld et al., 2015). Having a broad perspective on the neuropsychological characteristics of the FE as well as the factors that can condition its development, will allow to identify the sequence of normal development of this function (Lozano and Ostrosky, 2011).

Taking into account the previous information, the objective of this study is to analyze the profile of evolution of EF and IM in relation to the evolution of PF in preschool children.

MATERIAL AND METHOD

PARTICIPANTS

This study participated a total of 81 children aged between 3 to 6 years, 44 children and 37 girls, selected by convenience of 4 schools in the south of Spain both a rural and an urban environment. Inclusion criteria were taken into account: schooling in Early Childhood Education and not suffer physical and / or intellectual disability. The parents signed an informed consent for voluntary participation of the children in this investigation. The study was approved by the ethics committee of the University of Jaén.

MATERIALS AND TESTS

Through an ad hoc socio-demographic questionnaire relevant information was collected from the parents. As anthropometric parameters we analyzed the height (cm), which was measured with a stadiometer (Seca 222, Hamburg, Germany), and the weight (kg), which it was measured with a scale (634 Seca, Hamburg, Germany), and the body mass index (BMI) that was obtained from the equation, $BMI = \text{weight (kg)} / \text{height (m)}^2$. The circumference of the waist was measured by an ergonomic tape (Seca SE201, Germany). In the PF analysis, all the selected tests are validated in the preschool population by Latorre et al. (2015) and represent basic components of PF such as strength, strength, speed, responsiveness and balance. They are simple tests in their understanding for preschool children. In addition, the manual dynamometry test was added. The cardiorespiratory resistance was evaluated by the 10x20m test, inspired by the spatial structure of Léger, Mercier, Gadoury and Lambert (1988). Regarding the evaluation of the balance, the stork test was used (Johnson and Nelson, 1979). The *sprint* record was made over a distance of 20 meters (Fjørtoft, Pedersen, Sigmundsson and Vereijken, 2011). To analyze the reaction time (RT), the *Ruler Drop Test* (RDT) was used (Fong, Ng and Chung, 2013). The hand grip strength was analyzed using a CAMRY handhelddynamometer (EH101; Camry, Guangdong Province, China) that presents a range 0-90 kg with an accuracy of 0.1 kg, and an adjustable grip to take into account the different hand sizes, test validated in the preschool population by Latorre et al. (2017). Finally, leg strength was evaluated by the horizontal jump test (España-Romero et al., 2010).

The EF was analyzed by the Porteus labyrinth test (1965), in which 12 labyrinths of increasing complexity with pre-established routes are presented. The Porteus mazes test is a non-verbal intelligence test that allows the evaluation of a person's ability to make a plan. The test presents adequate values of internal consistency in children (Krikorian and Bartok, 1998).

The IM was analyzed using the drawing of the human figure Goodenough (GHDT), revised version (Harris, 1963). In the GHDT, children are asked to make two drawings, one of a man and the other of a woman. The evaluation focuses on the details and the general proportion of the body of a drawing of a man (73 data) and a woman (71 data). The GHDT

presents adequate reliability and validity compared to other intelligence tests in children aged 3 to 15 years (Abell, Horkheimer and Nguyen, 1998, Plubrukarn and Theeramanoparp, 2003). In this study, the average crude score of both drawings was used.

PROCESS

After obtaining the appropriate permits from the schools and the informed consent of the parents, the tests were applied. In three separate sessions 48 hours, the children were evaluated by a team of researchers trained in the different tests. On the first day the dynamometry tests were performed (two attempts with each hand), RDT (three attempts with each hand), balance (two attempts with each leg) and horizontal jump (two attempts). On the second day the test of 20 m (two attempts) and 10x20 m (one attempt) was recorded. On the third day the EF and IM tests were performed. Before conducting physical tests, children made based on continuous career and joint mobility warming also were conducted by the research team tests demonstration and children executed trials familiarization tests dynamometry, RDT, balance and horizontal jump. The best attempts in each test were selected except in the manual dynamometer, RDT and equilibrium which was performed on the average of the two hands and legs respectively with the best attempt. Each child was evaluated individually. All the tests were carried out in the sports facilities and classrooms of the selected schools. The children were encouraged to develop their best performance in each physical test.

STATISTIC ANALYSIS

The data of this study have been found through the statistical program SPSS., V.19.0 for Windows, (SPSS Inc, Chicago, USA). The level of significance was set at $p < .05$. The data are shown in descriptive statistics of mean, standard deviation and percentages. The normal distribution of the data and the equality of variances were verified by Kolmogorov-Smirnov and Levene contrast tests respectively. The differences between sexes and age groups were analyzed through analysis of variance (ANOVA) with post hoc analysis (Bonferroni). Finally, a Pearson correlation analysis and multiple linear regression between MI, EF and CF adjusted for age and sex were performed.

RESULTS

Table 1 shows the sociodemographic variables in relation to one of the parents.

Table 1. Sociodemographic variables in relation to one of the parents.

Civil status	%
Single	10.8
Married or in couple	85.1
Divorced / separated	4.1
Socioeconomic level	
Low	16.4
Medium	83.6
Level of studies	
Without studies	4.0
Primary	25.7
Secondary	39.2
University students	31.1

No socio - demographic variable caused significant differences in the PF or cognitive variables analyzed . Table 2 shows the results of age, anthropometric variables, cognitive variables and PF by sex. Only significant differences are found in the circumference of the hip that is greater in children.

Table 2. Age, anthropometric variables, cognitive variables and physical condition by sex.

	Boy	Girl	p-value
	Media (DT)	Media (DT)	
Age (months)	58.09 (13.15)	56.73 (13.13)	.644
BMI (Kg / m ²)	16.94 (2.04)	16.47 (1.51)	.257
Hip circumference (cm)	57.98 (5.15)	55.51 (2.92)	.012
Horizontal jump (cm)	77.74 (37.21)	74.97 (32.57)	.728
Speed, 20 m (s)	6.10 (1.25)	6.32 (1.18)	.410
Resistance (s)	91.35 (22.78)	91.63 (22.00)	.956
Balance (s)	10.32 (13.26)	11.17 (13.79)	.778
Dinamometry (kg)	6.67 (2.88)	6.25 (2.67)	.496
RDT (cm)	35.52 (11.29)	37.44 (8.69)	.400
IM (0-73)	6.56 (2.27)	7.65 (3.05)	.077
FAITH (3-15)	7.78 (2.72)	7.23 (2.82)	.373

SD: standard deviation. BMI: body mass index. RDT : *ruler drop test*. IM: intellectual maturity. EF: executive function.

Table 3 shows the evolution of cognitive and CF variables according to the age of the children. Significant differences are observed among all the variables in relation to the age groups.

Table 3. Evolution of cognitive variables and physical condition according to the age of the children.

	3 years Media (TD) n = 31 to	4 years Media (TD) n = 13 b	5 years Media (TD) n = 19 c	6 years Media (TD) n = 18 d	P-value	Effect size (η^2)	Analysis post-hoc
Horizontal jump (cm)	39.57 (18.01)	80.50 (18.15)	99.21 (16.13)	111.33 (17.11)	<.001	.763	a <b, c, d b <c, d
Speed, 20 m (s)	7.29 (0.96)	5.93 (0.93)	5.46 (0.86)	5.30 (0.54)	<.001	.534	a> b, c, d
Resistance (s)	112 .45 (16.87)	85.95 (17.89)	75.88 (12.57)	76.98 (11.61)	<.001	.561	a> b, c, d
Balance (s)	1.98 (3.26)	5.35 (3.57)	15.82 (13.77)	24.23 (15.36)	<.001	.458	a <c, d b <c, d
Dinamometry (kg)	3.83 (1.29)	5.73 (1.31)	8.50 (1.61)	9.45 (1.50)	<.001	.748	a <b, c, d b <c, d
RDT (cm)	40.96 (9.52)	37.80 (7.23)	35.65 (10.13)	28.30 (8.48)	<.001	.221	a> d
IM (0-73)	4.50 (2.21)	8.54 (2.33)	8.76 (1.44)	8.30 (1.37)	<.001	.546	a <b, c, d
FAITH (3-15)	5.37 (2.01)	7.11 (2.15)	8.63 (2.03)	10.38 (1.64)	<.001	.516	a <b, c, d b <d

SD: standard deviation. RDT : *ruler drop test*. IM: intellectual maturity. EF: executive function.

Figure 1 shows the evolution profile of the variables of FC and cognitive development throughout the age, a parallel evolution can be observed in the maturation of the PF, IM and the rest of the PF tests.

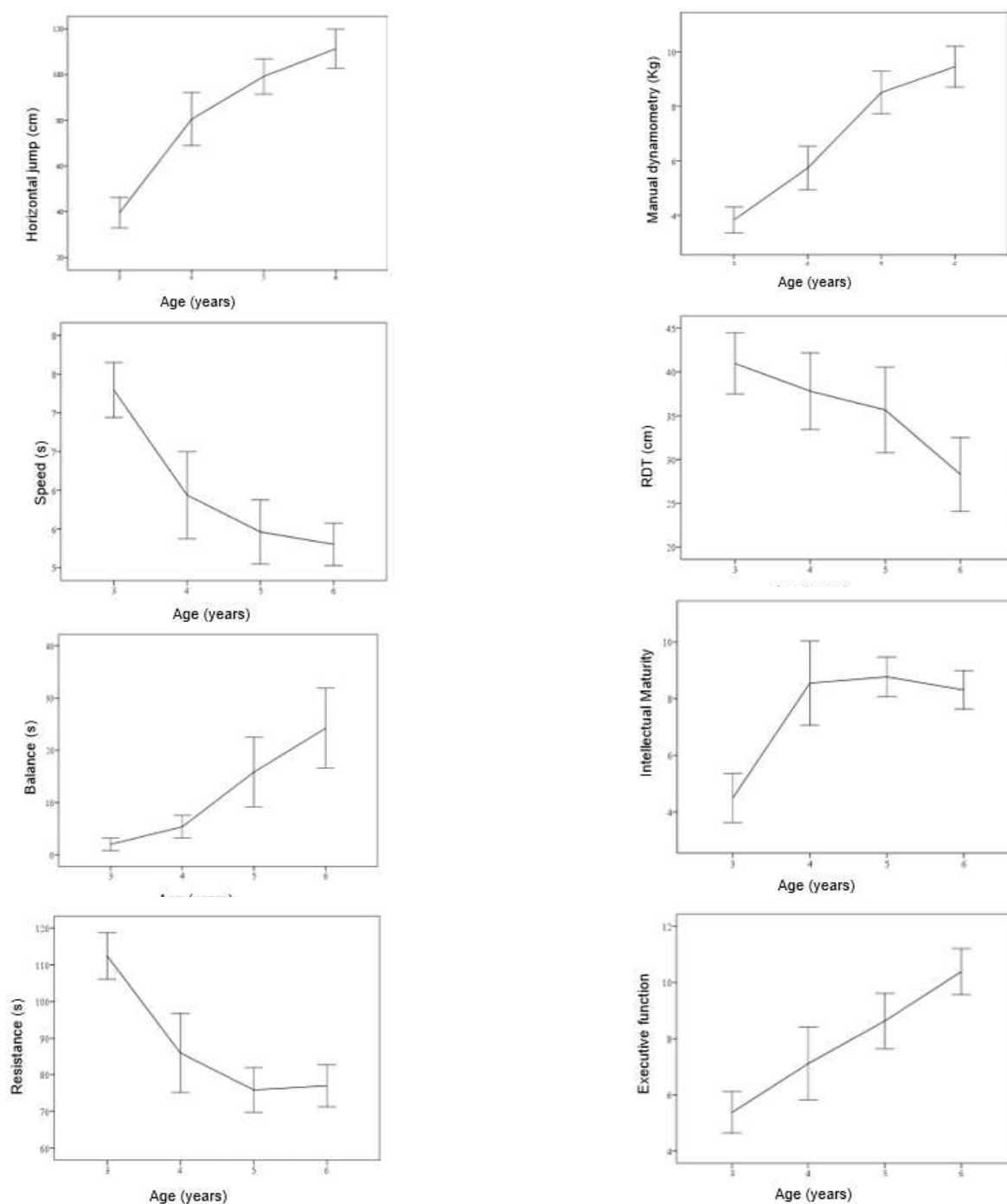


Figure 1. Evolution profile of cognitive variables and physical condition throughout the age.

The Pearson correlation analysis revealed that PF and IM correlated positively with each other ($r = 0.256$, $p < .027$), in addition, PF correlated negatively with RDT ($r = -0.223$, $p < .047$) and MI positively with manual dynamometry ($r = 0.244$, $p < .035$) and negatively with time in traversing 20 m ($r = -0.263$, $p < .022$). Figures 2,3 and 4 show the dispersion graphs between the IM with the hand

dynamometer and the time spent traveling 20 m and the scatter plot between the PF and the RDT.

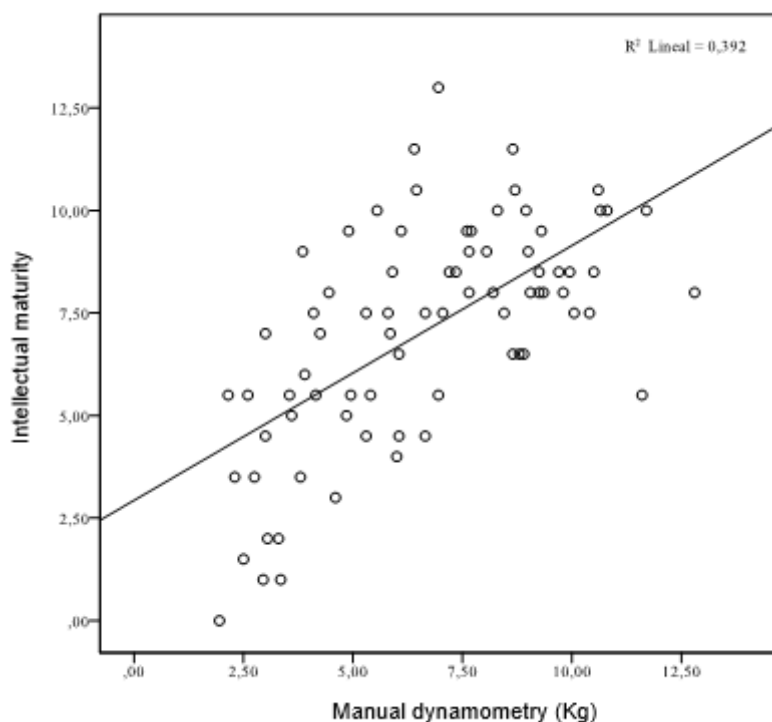


Figure 2. Scatter plot between intellectual maturity and manual dynamometry.

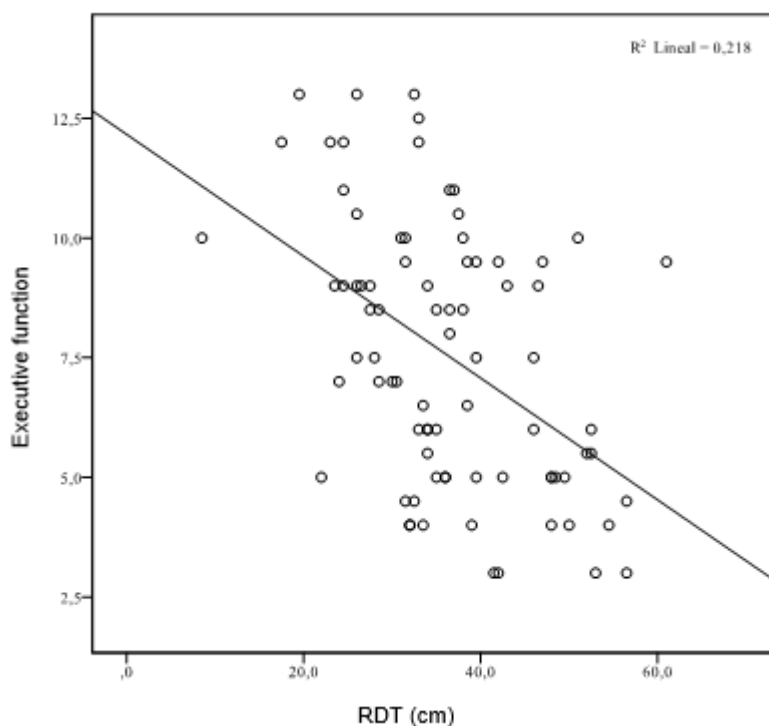


Figure 3. Graph of dispersion between intellectual maturity and the time used to travel 20 m.

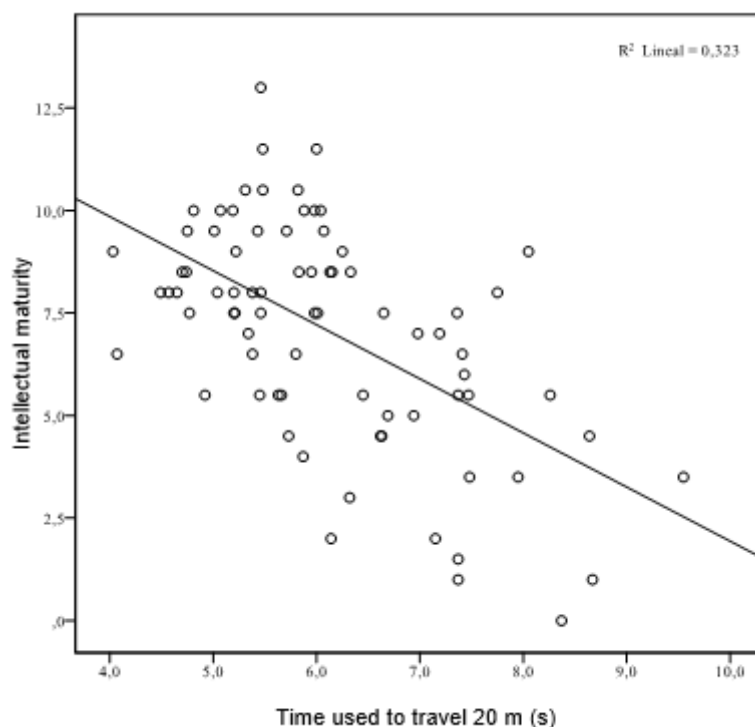


Figure 4. Dispersion chart between the executive functions and the Ruler Drop Test.

DISCUSSION

The aim of this study was to analyze the evolutionary profile throughout the age in preschool children of EF, IM and PF, which is a novel analysis in the interrelation between cognitive and physical development. The main finding of this study indicates that along the growth there is an evolutionary parallelism between the cognitive and FF variables. In addition, the speed of displacement, the hand dynamometry and the reaction time are variables associated with the MI to the FE at preschool ages.

In this sense, Krombholz (2012) shows a significant correlation between physical growth, the development of motor skills and cognitive performance in preschool children. Similarly, Wassenberg et al., (2005) point to a parallel development of cognitive and motor-specific performance in children during normal or delayed development as well as specific brain structures, such as, for example, the basal ganglia or frontal cortex and transmission of dopamine are shared in both cognitive performance and motor performance; so that motor performance is related to performance in several specific cognitive measures. In the same sense, Krombholz (2006) in a study with preschool children indicates significant correlations between measures of growth and physical performance, motor and cognitive performance, PF, coordination and manual dexterity, which improved in all groups old.

In this study, cardiorespiratory fitness has not shown any association with cognitive variables, however this ability is perhaps the most relationship with cognition, so aerobic capacity can be related to the structure and function of the

brain in the preadolescent (Chaddock et al., 2010). Methods with neuroimaging have been used to identify the mechanisms involved in the relationship between aerobic capacity and cognition in children (Chaddock et al., 2011). In turn, Chaddock et al. (2010) suggest that deficits in cognitive control associated with poorer aerobic capacity may be related to differences in basal ganglia volume and lower hippocampal volumes. Children who are in good physical shape have greater cortical activation and cognitive performance (Tompsonski, 2008). In this sense, various activities have been shown to improve children's PAs, such as aerobic work, martial arts and yoga (Diamond and Lee, 2011).

On the other hand, research focusing on the development of disorders such as hyperactivity, attention deficit and speech apraxia has suggested that cognitive and motor performance are associated (Wassenberg et al., 2005). Studies with subjects with Down syndrome show a relationship between motor competence and EFs (Schott and Holfelder, 2015). All these results indicate the parallel development of specific cognitive and motor functions in children, both with normal or delayed development.

In this study we have also found an association between IM and EF. Similarly, Rosenthal, Riccio, Gsanger and Jarratt (2006) found a relationship between EF and IM. Some of the aspects of the EF are involved with the GDHT scoring systems, so when drawing a human figure, a child must remember what aspects belong to an image of a person, such as eyes, nose, ears, etc., and must plan each part of the drawing (eyes, ears, hands, etc.). Therefore, these two tests of cognitive analysis can be a simple and practical resource for ecological studies, in this case in the school context itself.

During childhood and the preschool period, basic components of the EF develop, forming a fundamental base that will be the scenario for the development of the greater cognitive processes in adulthood (Garon et al., 2008). The early identification of children with motor problems is increasingly important in clinical practice especially due to its association with cognitive development. The present study provides interesting information for the analysis of the relationships between cognitive and motor performance, which has implications for establishing training and intervention programs in early childhood. These findings emphasize the early identification of children with deficient motor performance during the first school years.

The school represents an essential space for the promotion of physical activity (Fradejas, Espada and Garrido, 2016), however, currently in Spain, although Physical Education and physical activity are part of the curriculum of Early Childhood Education (Royal Decree 1630/2006, of December 29) and its recognition is important in the Educational Community (Latorre, 2007), the scarcity of adequate and safe material spaces and resources (Latorre, 2007) and possibly a deficient allocation of time Physical Education classes in Early Childhood Education, cause that a large part (approximately 60%) of teachers of Early Childhood Education indicate that Physical Education is not working sufficiently (Latorre, 2007). In this sense, it would be important to incorporate a specific schedule of Physical Education in Infant Education to improve the

levels of physical activity and CF and consequently the cognitive performance of children from 3 to 6 years. Legislative changes are also necessary to promote physical activity in Early Childhood Education in order to promote health, physical and cognitive development of children from 3 to 6 years. One of the limitations of this study is its transversal nature that forces us to be cautious in the results obtained and in the established causal relationships. However, a strength of this research is that to our knowledge, few studies have analyzed the association and evolution of cognitive and PF variables in preschool children in a school setting, which has important clinical and educational repercussions.

In conclusion, there is an evolutionary parallelism between cognitive development, specifically EF and IM, with the development of PF, the specific association of manual dynamometry, the speed of the race and the reaction time with the cognitive variables analyzed.

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