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Physical fitness and its association with cognitive performance in Chilean schoolchildren: The Cogni-Action Project

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This study aimed to establish the association and differences in a diversity of cognitive domains according to cardiorespiratory fitness (CRF), muscular fitness (MF), and speed-agility fitness (S-AF) level in a large sample of Chilean schoolchildren. 1171 Chilean schoolchildren aged 10–14 years participated. CRF, MF, and S-AF were assessed through the ALPHA-fitness test battery. Cognition was evaluated through the NeuroCognitive Performance Test, which involved eight tests related to four main domains: cognitive flexibility (CF), working memory (WM), inhibitory control (IC), and intelligence (IN). Both global (multivariate) and individual (univariate) analyses were performed to determine the differences in cognitive functioning according to low-, middle-, and high-fitness level. The global analyses showed a significant main effect for CRF, $F_{(16,940)} = 3.08$, $p \leq .001$ and MF groups, $F_{(16,953)} = 2.30$, $p = .002$, but not for S-AF, $F_{(16,948)} = 1.37$, $p = .105$. CRF shows a significant main effect in seven of eight tests, involving CF, WM, IC, and IN domains, whereas MF shows a significant main effect in five of eight tests without association with IN. SA-F shows a significant main effect only with IC. Statistical differences were found between the low- and middle/high-fitness groups but not between the middle- and high-fitness groups. At a global level, both CRF and MF seem to be associated with a higher cognitive profile in scholars; however, at an individual level, all fitness components show a favorable relationship to some cognitive domine. Then, future cognitive developing strategies should consider all fitness components, prioritizing those low-fitness schoolchildren.

KEYWORDS
adolescents, cognition, healthy lifestyle, muscle strength, physical fitness, schools

1 | INTRODUCTION

Growing scientific evidence supports that physical fitness is a potent marker of brain health throughout the life span.[1] Overall, systematic reviews have shown a strong relationship between physical fitness components such as cardiorespiratory fitness (CRF), muscular fitness (MF), and speed-agility fitness (S-AF) with cognitive function, academic achievement, and brain health in children and adolescents.[2–4] Indeed, having a high-fitness level may enhance both children's behavioral and biological aspects, transferring these benefits to the cognitive and educational field.[5]

Cardiorespiratory fitness has been the most studied component of physical fitness. To date, there is strong evidence displaying that children with a higher CRF level present greater levels of attention, working memory, and cognitive flexibility, and in turn, higher academic achievement.[1–3] Interestingly, even though some evidence exist on the association between MF and S-AF with academic achievement,[6] their relation to diverse cognitive domains is less consistent or unexplored.[7,8] At this moment and based on the current literature, it is possible to speculate that CRF, SA-F, and MF could be related to cognitive domains into a differentiated extent.[1,9,10] This idea considers that their underlying mechanisms, although they have not been identified completely, would not necessarily be the same.[1,10] For instance, CRF seems to elicit a beneficial impact on neurogenesis, cognitive function, and brain metabolism throughout a complex sequence of physiological events linked to the release of neurotrophic factors, which supports the existence of a muscle-brain endocrine loop.[9] However, the MF influence on the brain has been more specifically related to an enhanced neuromuscular and motor system properties.[10]

In addition to the above mentioned, there are still other concerns and gaps to cover in this matter; thereby, the present study focuses on two of them. On the one hand, cognition is a complex mental process which is fundamental to acquiring knowledge and achieve personal goals, and several cognitive domains form it.[11,12] For this reason, it is appropriated that cognition will be evaluated throughout a set of cognitive tasks in order to provide a more comprehensive approach and to generates more tailed public health and educational recommendations in this knowledge area. In this sense, this study supports the idea of exploring how each physical fitness component is related to a wide variety of cognitive abilities and domains.

On the other hand, it is possible to find scarce evidence studying the relationship between physical fitness and cognition in the Latin-American children population.[13] This gap not only is relevant to consider because most of the evidence published on this matter come from developed countries and thereby involve a more favorable social and educational contexts[13]; but also because it is well known that social vulnerability exerts a substantial and detrimental effect on children's brain health, cognition, and school achievement.[14–16] Besides, at the current rate, by 2030, around 63% of the world's children will be living in lower-middle-income nations like the most Latin-American countries.[17] In this way, nowadays, exploring factors helping to resolve this global concern is essential considering also the impact of the COVID-19 pandemic on the rate of poverty in this region.[18] Therefore, this study aimed to establish the association and differences in a diversity of cognitive tests and domains according to the level of CRF, MF, and S-AF in a large sample of Chilean schoolchildren.

2 | METHODS

2.1 | Study design

This study is part of the Cogni-Action Project, which seeks to establish the associations of physical activity, sedentarism, and physical fitness with brain structure and function, cognitive performance, and academic achievement in Chilean schoolchildren.[19] This project was approved by the Ethics Committee of the Pontificia Universidad Católica de Valparaíso (BIOEPUCV-H103–2016) and was retrospectively registered (8/July/2020) in the Research Registry (ID: researchregistry5791). In all aspects, this research has been conducted according to the Declaration of Helsinki. Written consents have been obtained before participation from the school principal, parents, and assent from participants.

This cross-sectional study was carried out from March 2017 to October 2019, where children and adolescents in grades 5th to 8th were recruited from the public, voucher, and private schools in the Valparaiso region, Chile. This study was prepared according to the STROBE guidelines

(Strengthening the Reporting of Observational Studies in Epidemiology) for cross-sectional studies.[20]

2.2 | Study population

Total sample size and power calculations were based on the total enrollment of schoolchildren in the Valparaiso region (5th to 8th grades) indicated by the Chilean Ministry of Education in the year 2016 (universe $N = 951\ 962$). It was considered an alpha error of 5%, confidence interval of 99%, heterogeneity of 50%, and a 20% dropout. Hence, a total of 797 participants were necessary to reach a representative sample size from the second most populated region in Chile.

The general inclusion criteria were girls and boys from 5th to 8th grades (10–14 years old), and for ethical reasons, children who present any physical, psychiatric, and/or psychological disability were also included in this project study if both children and parents approve their participation, through the signing of assent and consent, respectively. Finally, 1586 schoolchildren were involved in this project due to the elevated participation and minimal exclusion criteria to maximize diversity in social, biological, and environmental influences. For this study, 1171 schoolchildren were included after applying the following exclusion criteria: (a) being out of the stipulated age range, (b) missed the cognitive evaluation or (c) not having data on any of the variables involved for this study. In this sample, were also included 111 children who participated in a national program to improve their learning level.

2.3 | Measurements

All assessments took place at schools, considering two sessions of four hours each separated by eight days apart. In the first session, a complete cognitive battery and anthropometric measurements were assessed, while during the second session, physical fitness was evaluated. Trained instructors from our research team performed all evaluations, and schoolchildren had a brief familiarization trial before each test.

2.4 | Physical fitness assessment

Physical fitness was evaluated through the well-documented ALPHA-fitness test battery.[21] Briefly, this time-efficient and low-cost fitness battery was developed to provide a set of valid, reliable, feasible, and safe field-based fitness tests in children and adolescents. It permits evaluating and monitoring a large number of children simultaneously. The ALPHA-fitness test battery presents three slightly different versions which depend on the available time to administer the tests; in this study, we have used the extended version that includes all main physical fitness components (CRF, MF, and S-AF).[21] Tests were performed in sports fields or indoor gym during mornings (between 9:30 and 12:00), suggesting appropriate sportswear. Verbal instructions on how to perform each test and a brief demonstration of the technique were carried out to ensure the optimal test performance. Children practiced each test previously and then started when they felt secure.

2.4.1 | Cardiorespiratory fitness

Cardiorespiratory fitness was evaluated with the 20-m shuttle run test and carried out at the end of the evaluation session.[21] Groups of between 8 and 10 children were located at the starting line, and a sound signal indicated the run rhythm, which started at 8.5 km/h and increased 0.5 km/h every minute. Thus, children had to run 20 m and wait on the second line until the next sound signal. To ensure a progressive increase and a correct adaptation to the test, a physical education teacher ran beside children guiding the first two minutes of the test. The test ended voluntarily when the child was fatigued or unable to reach the line twice. Total time (in seconds) and the number of completed stages were registered, as recommended.[22] Thus, a *z*-score of the total time (s) based on sex and age was created as a normalized CRF score.

2.4.2 | Muscular fitness

Upper and lower limb strength were evaluated as indicators of MF.[21] On the one hand, upper limb strength was assessed by the maximum handgrip strength test using a dynamometer (Jamar Plus+ Digital Hand Dynamometer, Sammons Preston). The dynamometer was previously adjusted to the child's hand size, allowing for measures of 0–90 kg, with a 0.1 kg precision. This test was performed twice (both hands), in a standing position with a fully extended elbow, and the maximum score between measures was used. Then, in order to create a relative measure of upper limb strength, the score was divided by body weight.

On the other hand, the lower limb strength was assessed through the standing long jump test. A starting line was fixed on the floor, and children had to stand with their feet parallel behind the line. At the verbal signal, children had to jump as far as possible starting with and landing on both feet at the same time. This test was performed twice (with at least 1-min rest between them), and the longest jump was recorded in centimeters (cm). Finally, the MF score was created based on the sum of the sex- and age-standardized values of handgrip/weight and standing long jump.

2.4.3 | Speed-agility fitness

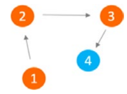
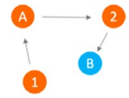
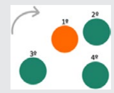
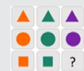
Speed-agility fitness was assessed using the 4 × 10-m shuttle run test.[21] This test accounts for speed of movement, agility, and coordination. Two lines (5 m long) separated by 10 m were fixed on the floor, and two cones were located in each line. Children had to run as fast as possible, taking a cloth located ~50 cm after the first line and carrying it to the next line where they had to swap for a second cloth before running to the final line. The test was performed twice, and the fastest time was recorded in seconds. Time was multiplied by −1, so a higher score indicated better performance. Finally, a *z*-score base on sex and age was created as a normalized S-AF score.

2.5 | Cognitive performance

The NeuroCognitive Performance Test (NCPT) from Lumos Labs, Inc. was used to assess the children's cognitive performance.[23] The NCPT has demonstrated adequate reliability and validity as a measure of cognitive performance, and good concordance with pencil-paper assessments.[23] It is a brief, repeatable, web-based platform to measure several cognitive domains, including working memory, visuospatial memory, psychomotor speed, fluid and logical reasoning, response inhibition, numerical calculation, and selective and divided attention.

The NCPT was applied in schoolrooms, in groups of 25 children, each one with a laptop. The entire session lasted around one hour, which consisted of a brief explanation about the session's aim, a demonstration and practice before each test, and finally the execution. Children's answers were resolved before starting each cognitive test. Table 1 displays a summary of all eight cognitive tests assessed in the NCPT. More details about tests are elsewhere.[19,23] In order to facilitate results description and its discussion, we grouped the cognitive test into four domains based on literature and also the main cognitive ability of each task, in summary: (a) Cognitive flexibility (TMT-A, TMT-B, and digit symbol coding tests), (b) Working memory (forward and reverse memory span tests), (c) Inhibitory control (go/no-go test), and (d) Intelligence (problem-solving and progressive matrices tests) (details in Table 1). Despite the aforementioned, all analyses were individually performed to explore differences depending on fitness level and in order to detect any possible cognitive particularity. Each test was scaled following a normal inverse transformation of the percentile rank.[23] These procedures provide the benefit of having scaled scores derived on the same normal distribution with a mean of 100 and a standard deviation of 15.

TABLE 1 Domains and tests from The NeuroCognitive Performance Test

Domain	Cognitive tests	Cognitive functions involved	Graphical representation
CF	Trail making test A	Attention, cognitive flexibility, and processing speed	
	Trail making test B	Attention, cognitive flexibility, and processing speed	
	Digit symbol coding	Processing speed	
WM	Forward memory span	Visual short-term memory	
	Reverse memory span	Working memory	
IC	Go/no-go test	Inhibitory control and processing speed	
IN	Balance scale	Quantitative and analogical reasoning	
	Progressive matrices	Problem-solving and fluid reasoning/intelligence	

Abbreviations: CF, cognitive flexibility; IC, inhibitory control; IN, intelligence; WM, working memory.

2.6 | Covariates

Sex, school administration, peak height velocity (PHV), and body mass index (BMI) were used as covariates in all models. These covariates were chosen by previous evidence indicating its influence on cognitive performance,[1–3,6,7] and also based on our own exploratory analysis (using a stepwise regression approach) in this sample. Sex was included due to diverse differences between boys and girls on the main topic of this study.[24] The school administration (public, voucher, or private) was included as a covariate due to their strong association with cognitive, physical fitness, and academic performance.[15,16] School administration is a close indicator of socioeconomic and parental education levels in the Chilean context.[25] PHV was calculated as a maturity status indicator.[26] It was computed by subtracting the PHV age from the chronological age. The difference in years was defined as a value of maturity offset. Finally, the weight was measured with a digital balance in which precision and maximum weight were of 0.1 and 150 kg, respectively (OMROM, HN-289-LA), while height with a portable stadiometer (SECA, model 213, GmbH). Then, the BMI z-score was calculated using World Health Organization 2007 growth reference for school-aged children.[27]

2.7 | Statistical analysis

Descriptive analyses are presented as means, standard deviation, frequency, and percentage. Quantitative variables were checked for normal distribution using the Kolmogorov–Smirnov test. Differences between boys and girls in continuous and factor variables were tested using the Student's t test for equal variances and the Chi-square test, respectively. Physical fitness was grouped into low (corresponding to quartile 1), middle (corresponding to quartile 2- quartile 3), and high (corresponding to quartile 4), as previously used in this field.[28] To reduce the chances of Type I error from multiple comparisons and to test the "global main effect," three multivariate analyses of covariance (MANCOVA) were conducted investigating group differences (low-, middle-, and high-fitness level), using the percentile score of the eight cognitive tests as a continuous outcome, and each fitness variable (CRF, MF, and S-AF) as an explanatory factor, including sex, school administration, PHV, and BMI as covariates. Whereas to test the "individual main effect," one-way analysis of covariance (ANCOVA) was performed to assess mean differences between fitness level groups in each cognitive test, including the same covariates mentioned above in the models. Finally, post hoc pairwise comparisons were conducted to establish differences in the marginal estimated means in each pair of groups (low- vs. middle-, low- vs. high-, and middle- vs. high-fitness level), and p-values were corrected using Tukey contrasts. Additionally, effect size (ES) estimation was calculated using *emmeans* package in R. Consequently, the ES was interpreted as no effect (<0.2), small (0.2 < 0.5), medium (0.5 < 0.8), and large (≥0.8).[29] Finally, as the interaction by sex was not significant ($p > .1$), all analyses are presented together (boys and girls). Assumptions of linearity, normality, multicollinearity, and homoscedasticity were plotted, inspected, and verified. All analyses used complete case data, and no imputation was carried out. All statistical analyses were performed in R (version 3.6.1; R Foundation for Statistical Computing), and statistical significance was set at $p < .05$.

3 | RESULTS

Table 2 presents the main participant characteristics. Significant differences were found in PHV, weight, CRF, SLJ, HGS, S-AF.

TABLE 2 Main characteristics of the participants

Variables	All *n*		Boys *n*		Girls *n*		*p*-Value
Age (years)	1171	12.23 ± 1.04	591	12.19 ± 1.03	580	12.26 ± 1.06	.311
PHV (years)		−0.55 ± 1.20		−1.30 ± 0.90		0.21 ± 0.98	**<.001**
Weight (kg)		50.37 ± 11.85		49.54 ± 11.89		51.21 ± 11.76	**.016**
Height (cm)		152.52 ± 9.15		152.48 ± 10.05		152.57 ± 8.13	.855
BMI (*z*-score)		1.04 ± 1.06		1.08 ± 1.08		1.01 ± 1.03	.257
BMI categories (*n*, %)							
Normal weight		559 (47.7)		279 (47.2)		280 (48.3)	.179
Overweight		363 (31.0)		174 (29.4)		189 (32.6)	
Obese		249 (21.3)		138 (23.4)		111 (19.1)	
School type (*n*, %)							
Public		405 (34.6)		197 (33.3)		208 (35.9)	.130
Voucher		488 (41.7)		263 (44.5)		225 (38.8)	
Private		278 (23.7)		131 (22.2)		147 (25.3)	
CRF (s)	952	261.38 ± 131.93	480	301.83 ± 141.92	472	220.25 ± 106.29	**<.001**
SLJ (cm)	972	140.84 ± 27.19	485	148.23 ± 27.68	487	133.47 ± 24.61	**<.001**
HGS	1164	0.45 ± 0.10	585	0.47 ± 0.11	579	0.44 ± 0.09	**<.001**
S-AF (s)	960	13.04 ± 1.34	481	12.69 ± 1.33	479	13.39 ± 1.25	**<.001**

Note: Values are presented as mean ± SD or frequency and percentage. Values in bold indicate significant differences. p-Value corresponding to t-test between boys and girls.

Abbreviations: BMI, body mass index (BMI-for-age Z-score and categories were calculated using WHO 2007 growth reference)[27]; CRF, cardiorespiratory fitness (measured by the 20-m shuttle run test); handgrip (kg)/body weight (kg)); HGS, handgrip strength (relative values; PHV, peak height velocity offset; S-AF, speed-agility fitness (measure by the 4 × 10-m shuttle run test); SLJ, Standing long jump.

Figure 1 shows a significant main effect on CRF and MF fitness components (Figure 1A, $p < .001$; and Figure 1B, $p = .002$, respectively), but not on S-AF ($p = .105$, Figure 1C). Additionally, Figure 1 shows significant main differences in seven (p's $\leq .021$), five (p's $\leq .020$), and two (p's $\leq .023$) cognitive tests according to CRF, MF, and S-AF components, respectively.

Table 3 shows analyses of pairwise comparisons and ES according to CRF groups. There were significant differences between low vs. middle and low vs. high groups in cognitive flexibility (trail making test A and B, and digit symbol coding), working memory (forward and reverse memory span), inhibition control (go/no-go), and intelligence domains (progressive matrices) (all p's $\leq .035$). All of these differences presented a small ES ($d = 0.204$–0.446). Furthermore, only a difference was found between the low vs. middle group in the trail making test B ($p = .014$ and $d = 0.230$), as well as between low versus high groups in the go/no-go test ($p = .001$ and $d = 0.346$). No differences were found between middle versus high groups in the rest of the tests. Also, no difference among groups was observed in the problem-solving test.

Table 4 displays analyses of pairwise comparisons and ES according to MF groups. There were significant differences between low versus middle and low versus high groups in one test from working memory and inhibition control domains (forward memory span and go/no-go test, respectively) (all p's $\leq .34$). All of these associations presented a small ES ($d = 0.204$–0.373). Furthermore, only differences between low versus middle groups were found in five tests, corresponding to cognitive flexibility (trail making test A and digit symbol coding), working memory (reverse and forward memory span), and inhibition control domains (go/no-go test) (all p's $\leq .034$, $d = 0.204$–0.373). No differences were found between middle vs. high groups in the remaining tests.

Table 5 shows analyses of pairwise comparisons and ES according to S-AF groups. There were significant differences between low versus middle and low versus high groups only in the working memory domain (reverse memory span test, p's $\leq .046$; $d = 0.217$–0.224). Furthermore, only a difference between low versus high groups was found in the inhibition control domain (go/no-go test, $p = .014$, $d = 0.263$). No differences were found between middle vs. high groups in the rest of the tests.

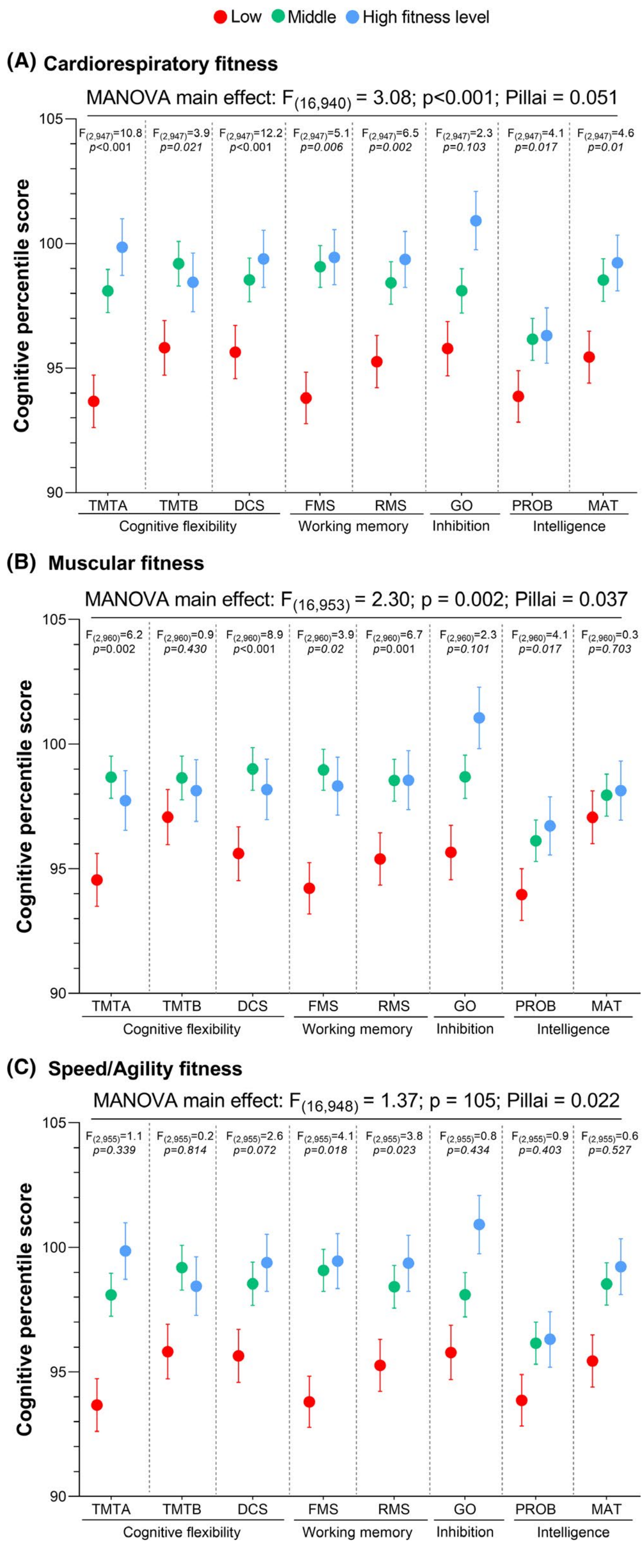


FIGURE 1 Multivariate cognitive effect according to each fitness component. DSC, Digit symbol coding; FWS, Forward memory span; GO, go/no-go; MAT, Progressive matrices; PROB, Problem-solving; RMS, Reverse memory span; TMT-A, Trail making test A; TMT-B, Trail making test B

4 | DISCUSSION

The present study aimed to determine the association and differences in diverse cognitive domains according to groups of CRF, MF, and S-AF levels in a large sample of Chilean schoolchildren. Our analysis indicates that CRF and MF, but not S-AF presented a global significant main effect on cognitive performance. At an individual level, CRF was associated with the four cognitive domains analyzed (cognitive flexibility, working memory, inhibition control, and intelligence), while MF was associated with three cognitive

TABLE 3 Pairwise comparison, according to cardiorespiratory fitness groups for each cognitive task

Domains	Cognitive task	Comparison	Diff ± SE	*t*-Value	*p*-Value	95% CI	Effect size
CF	Trail making test A	Low vs. middle	4.409 ± 1.165	3.785	**<.001**	1.682 to 7.136	0.311
		Low vs. high	6.316 ± 1.393	4.534	**<.001**	3.054 to 9.577	0.446
		Middle vs. high	1.907 ± 1.149	1.66	.219	−0.782 to 4.596	0.135
	Trail making test B	Low vs. middle	3.378 ± 1.208	2.797	**.014**	0.551 to 6.205	0.230
		Low vs. high	2.672 ± 1.444	1.85	.152	−0.708 to 6.053	0.182
		Middle vs. high	−0.706 ± 1.191	−0.593	.823	−3.493 to 2.082	−0.048
	Digit symbol coding	Low vs. middle	2.906 ± 1.174	2.475	**.035**	0.156 to 5.655	0.204
		Low vs. high	3.769 ± 1.404	2.684	**.020**	0.481 to 7.057	0.264
		Middle vs. high	0.863 ± 1.158	0.746	.734	−1.848 to 3.574	0.060
WM	Forward memory span	Low vs. middle	5.268 ± 1.137	4.634	**<.001**	2.606 to 7.93	0.381
		Low vs. high	5.705 ± 1.36	4.196	**<.001**	2.522 to 8.889	0.413
		Middle vs. high	0.437 ± 1.121	0.39	.919	−2.188 to 3.062	0.032
	Reverse memory span	Low vs. middle	3.167 ± 1.152	2.749	**.017**	0.47 to 5.865	0.226
		Low vs. high	4.121 ± 1.378	2.991	**.008**	0.895 to 7.347	0.294
		Middle vs. high	0.954 ± 1.136	0.839	.676	−1.706 to 3.614	0.068
IC	Go/no-go	Low vs. middle	2.334 ± 1.201	1.942	.126	−0.479 to 5.147	0.160
		Low vs. high	5.053 ± 1.437	3.517	**.001**	1.689 to 8.417	0.346
		Middle vs. high	2.719 ± 1.185	2.295	.056	−0.054 to 5.493	0.186
IN	Problem-solving	Low vs. middle	2.306 ± 1.14	2.023	.106	−0.363 to 4.975	0.166
		Low vs. high	2.414 ± 1.363	1.771	.178	−0.778 to 5.606	0.174
		Middle vs. high	0.108 ± 1.124	0.096	.995	−2.524 to 2.74	0.008
	Progressive matrices	Low vs. middle	3.081 ± 1.151	2.678	**.020**	0.387 to 5.775	0.220
		Low vs. high	3.897 ± 1.376	2.832	**.013**	0.675 to 7.119	0.279
		Middle vs. high	0.816 ± 1.135	0.72	.750	−1.84 to 3.473	0.058

Note: Values in bold indicate significant differences and effect size ≥0.20 (small effect).

Abbreviations: CF, cognitive flexibility; CI, confidence interval; Diff, difference of marginal mean value of ANCOVA adjusted for peak height velocity, sex, school type, and body mass index; Effect size by Cohen; IC, inhibitory control; IN, intelligence; *p*-value adjusted for multiple comparisons using Tukey contrasts; SE, Standard error; WM, working memory.

domains (cognitive flexibility, working memory, and inhibition control), and finally, S-AF was associated with two cognitive domains (working memory and inhibition control). Moreover, differences were observed principally between low and middle or high physical fitness groups, but not between the middle and high group. Interestingly, reverse memory spam and go/no-go tests, which involved cognitive abilities such as working memory, inhibitory control, and processing speed (linked to executive function), were associated with all three fitness components.

Several systematic reviews and meta-analyses support the main findings of this study.[4,15] Our results reveal that CRF has a strong association both at a global and individual level with all cognitive tests except with the problem-solving test. Despite this unique not significant association, CRF was linked to at least one test within the four cognitive domains. These findings are in line with the vast literature in developing countries showing that CRF is the most significant component of physical fitness related to attention capacity,[7,30,31] cognitive flexibility,[4] working memory,[30] inhibitory control,[32] and intelligence.[32] Multiple underlying bases explain the beneficial CRF impact on cognition, including molecular mechanisms, and structural and functional brain outcomes.[1,33] However, as MF and SA-F have been investigated scarcely, the effect and plausible mechanisms of each one on the brain remain unclear yet.

Regarding MF, our findings show a significant association both at a global and individual level. MF was related to cognitive flexibility (trail making test A and digit symbol coding), working memory (forward and reverse memory span), and inhibition control (go/no-go). Previous studies have found a relation between MF and working memory; nonetheless, this association seems to be dependent on CRF.[7,8] In children with overweight or obesity, the association of MF with the cognitive flexibility and planning ability shows a borderline association, while

TABLE 4 Pairwise comparison, according to muscular fitness groups for each cognitive task

Domains	Cognitive task	Comparison	Diff ± SE	*t*-Value	*p*-Value	95% CI	Effect size
CF	Trail making test A	Low vs. middle	4.192 ± 1.167	3.592	**.001**	1.462 to 6.922	0.295
		Low vs. high	3.162 ± 1.444	2.19	.072	−0.214 to 6.539	0.222
		Middle vs. high	−1.03 ± 1.172	−0.878	.651	−3.772 to 1.713	−0.072
	Trail making test B	Low vs. middle	1.599 ± 1.21	1.322	.379	−1.231 to 4.43	0.108
		Low vs. high	1.076 ± 1.497	0.719	.749	−2.426 to 4.578	0.073
		Middle vs. high	−0.523 ± 1.216	−0.431	.902	−3.367 to 2.32	−0.036
	Digit symbol coding	Low vs. middle	3.415 ± 1.182	2.89	**.011**	0.65 to 6.179	0.237
		Low vs. high	2.599 ± 1.462	1.778	.175	−0.821 to 6.019	0.181
		Middle vs. high	−0.816 ± 1.187	−0.687	.768	−3.593 to 1.961	−0.057
WM	Forward memory span	Low vs. middle	4.792 ± 1.137	4.216	**<.001**	2.133 to 7.451	0.346
		Low vs. high	4.093 ± 1.406	2.911	**.01**	0.804 to 7.383	0.296
		Middle vs. high	−0.698 ± 1.142	−0.612	.811	−3.37 to 1.973	−0.050
	Reverse memory span	Low vs. middle	3.165 ± 1.155	2.74	**.017**	0.463 to 5.868	0.225
		Low vs. high	3.185 ± 1.429	2.228	.066	−0.159 to 6.528	0.226
		Middle vs. high	0.019 ± 1.161	0.017	1.000	−2.696 to 2.735	0.001
IC	Go/no-go	Low vs. middle	2.98 ± 1.199	2.485	**.034**	0.175 to 5.785	0.204
		Low vs. high	5.442 ± 1.483	3.668	**.001**	1.972 to 8.912	0.373
		Middle vs. high	2.462 ± 1.205	2.044	.101	−0.356 to 5.279	0.169
IN	Problem-solving	Low vs. middle	2.141 ± 1.138	1.881	.142	−0.522 to 4.804	0.154
		Low vs. high	2.785 ± 1.408	1.977	.116	−0.51 to 6.079	0.201
		Middle vs. high	0.644 ± 1.144	0.563	.838	−2.032 to 3.319	0.046
	Progressive matrices	Low vs. middle	0.946 ± 1.159	0.816	.69	−1.766 to 3.657	0.067
		Low vs. high	1.048 ± 1.434	0.731	.742	−2.306 to 4.402	0.074
		Middle vs. high	0.102 ± 1.165	0.088	.996	−2.621 to 2.826	0.007

Note: Values in bold indicate significant differences and effect size ≥0.20 (small effect).

Abbreviations: CF, cognitive flexibility; CI, confidence interval; Diff, difference of marginal mean value of ANCOVA adjusted for peak height velocity, sex, school type, and body mass index; Effect size by Cohen; IC, inhibitory control; IN, intelligence; *p*-value adjusted for multiple comparisons using Tukey contrasts; SE, standard error; WM, working memory.

no association was observed with inhibitory control.[32] In the case of Latin-American children, the MF was favorably associated with attention capacity, but this result was moderate by their fatness level.[34] Contrary, MF was not associated with attention capacity or cognitive control in European[7] and Australian[8] adolescents, respectively. The last mentioned also supports one of the gaps in this research scenario regarding the apparent differences among countries and ethnicities due to their social and economic disparities.[14,15] Finally, even though it is possible to appreciate divergences respect to the relation between MF and cognitive functions, our results provide novel evidence that, in the present population, there is a clear association between them.

Concerning S-AF, this component was significantly associated only at an individual level with working memory and inhibitory control (reverse memory span and go/no-go test, respectively). Similar findings were found in Switzerland pre-schoolers, indicating a significant relationship between S-AF with memory and attention performance.[35] In Latin-American children, all fitness components were associated with children's attention capacity.[34] In general, although the evidence that addresses MF and S-AF is more limited and inconsistent than CRF, some studies show a positive association between S-AF and MF with higher gray matter volumes in diverse brain regions.[6] As occur with CRF, these findings between S-AF and MF with brain matter volumes might support a better cognitive profile in children and adolescents.[1]

Overall, our results support the favorable association between three physical fitness components and cognitive performance in children and adolescents of an underexplored Latin-American country, which contributes to the geographical gap on this research area.[13] Besides, we observe a small ES in most of the significant association between fitness components and cognition tests; however, at a public health

TABLE 5 Pairwise comparison, according to speed-agility groups for each cognitive task

Domains	Cognitive task	Comparison	Diff ± SE	*t*-Value	*p*-Value	95% CI	Effect size
CF	Trail making test A	Low vs. middle	−0.957 ± 1.145	−0.836	.679	−3.641 to 1.727	−0.067
		Low vs. high	0.537 ± 1.342	0.400	.915	−2.608 to 3.683	0.038
		Middle vs. high	1.494 ± 1.137	1.314	.385	−1.17 to 4.159	0.105
	Trail making test B	Low vs. middle	0.349 ± 1.18	0.296	.953	−2.415 to 3.113	0.024
		Low vs. high	0.858 ± 1.383	0.62	.808	−2.382 to 4.098	0.058
		Middle vs. high	0.509 ± 1.171	0.435	.900	−2.235 to 3.253	0.035
	Digit symbol coding	Low vs. middle	1.342 ± 1.155	1.163	.474	−1.362 to 4.047	0.093
		Low vs. high	1.7 ± 1.353	1.256	.418	−1.47 to 4.87	0.118
		Middle vs. high	0.358 ± 1.146	0.312	.947	−2.328 to 3.043	0.025
WM	Forward memory span	Low vs. middle	1.844 ± 1.117	1.652	.223	−0.772 to 4.461	0.132
		Low vs. high	2.934 ± 1.309	2.241	.064	−0.133 to 6.001	0.211
		Middle vs. high	1.09 ± 1.109	0.983	.586	−1.508 to 3.687	0.078
	Reverse memory span	Low vs. middle	3.053 ± 1.131	2.699	**.019**	0.403 to 5.703	0.217
		Low vs. high	3.153 ± 1.326	2.378	**.046**	0.046 to 6.259	0.224
		Middle vs. high	0.1 ± 1.123	0.089	.996	−2.532 to 2.731	0.007
IC	Go/no-go	Low vs. middle	2.18 ± 1.174	1.857	.151	−0.571 to 4.932	0.149
		Low vs. high	3.852 ± 1.377	2.799	**.014**	0.627 to 7.078	0.263
		Middle vs. high	1.672 ± 1.166	1.434	.321	−1.06 to 4.404	0.114
IN	Problem-solving	Low vs. middle	0.71 ± 1.113	0.638	.798	−1.898 to 3.318	0.051
		Low vs. high	1.711 ± 1.305	1.312	.387	−1.346 to 4.768	0.123
		Middle vs. high	1.001 ± 1.105	0.906	.634	−1.588 to 3.591	0.072
	Progressive matrices	Low vs. middle	−0.394 ± 1.126	−0.35	.934	−3.033 to 2.245	−0.028
		Low vs. high	0.784 ± 1.32	0.594	.822	−2.309 to 3.877	0.056
		Middle vs. high	1.178 ± 1.118	1.054	.541	−1.442 to 3.798	0.084

Note: Values in bold indicate significant differences and effect size ≥0.20 (small effect).

Abbreviations: CF, cognitive flexibility; CI, confidence interval; Diff, difference of marginal mean value of ANCOVA adjusted for peak height velocity, sex, school type, and body mass index; Effect size by Cohen; IC, inhibitory control; IN, intelligence; *p*-value adjusted for multiple comparisons using Tukey contrasts; SE, standard error; WM, working memory.

and educational context, even a small effect is meaningful when considering that each cognitive capacity could be affected (positively and negatively) by a vast multitude of internal and external factors (eg, sleep quality, fatness, social vulnerability, and others).[1,16,34]

Finally, it is essential to highlight that the degree of association between a specific cognitive domain would depend on the brain relationship with each fitness component. Thereby, we could speculate based on the scientific literature that the CRF influence on the brain would be linked to the increased physiological response to cover the oxygen and energy exercise demand.[1,33,36] In contrast, MF would be associated with a direct neuromuscular mechanism boosting the strength and power demand,[10,37] and S-AF would be related to the high demand of coordination and a mix between power strength and aerobic capacity.[38,39] Thus, increasing the level of children' CRF, MF, and S-AF, and not focusing in only one fitness component, could play an essential role related to an enhanced global cognition performance, which consequently may help to improve both academic achievement and brain health in children and adolescents.[1–3,7,11,40] Intervention studies are needed to corroborate the last mentioned.

4.1 | Strengths and limitations

Strengths of the present work include that, to the best of our knowledge, this is the first study in Latin-America using a large sample of schoolchildren exploring the association between different physical fitness components and several cognitive domains. Besides, both keys variables in this study, fitness and cognition, were evaluated using an extensive set of physical and cognitive tests, giving a general and not a particular view of their relationship. Finally, our results were significant and consistent even adjusted to several covariates that present a strong association with cognition (sex, school administration, PHV, and BMI). However, the principal study limitation is that the Cogni-Action Project employed a cross-sectional design, precluding inferences about causality.

5 | CONCLUSION

In conclusion, children and adolescents with higher fitness levels present a superior global and individual cognitive performance. Also, each fitness component showed a differentiated association degree with each cognitive task and domain. Therefore, both children and adolescents with the lowest level of fitness, and all three fitness components (CRF, MF, and S-AF), not just one, must be considered as interventional targets associated with a better cognitive profile in Latin-American schoolchildren. Intervention studies are needed to corroborate our findings and establish the independent influence of each fitness component over cognition.

CONFLICT OF INTERESTS

The authors declare to have no competing interests.

AUTHORS' CONTRIBUTIONS

CC-M designed the research; CC-M, PS-U, JS-M, and JO-A conducted research; CC-M and PS-U analyzed data, CC-M and PS-U wrote the paper; JCP, KPS, GLMF, FR-R, AG, and CFF critically reviewed the manuscript; CC-M had primary responsibility for final content. All authors provided critical feedback on the manuscript and read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

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

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