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CLINICAL RESEARCH ARTICLE

Relation between physical fitness and executive function variables in a preschool sample

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BACKGROUND: This study examined the association between key components of physical fitness with inhibition and cognitive flexibility in preschoolers.
METHODS: This was a cross-sectional study of 362 Spanish preschoolers. The key components of physical fitness and executive functioning were measured.
RESULTS: The partial correlation controlling for body mass index and family socioeconomic status showed that inhibition was positively related to cardiorespiratory fitness. No association was found between muscular strength (i.e., standing long jump and dynamometry) and speed/agility with inhibition or between physical fitness components and cognitive flexibility. The inhibition mean scores were significantly higher in preschoolers with higher cardiorespiratory than in their peers who were in lower categories, after adjustments were made for confounders. Additionally, the results showed that cardiorespiratory fitness was a significant predictor of inhibition, but for cognitive flexibility, age was the only significant predictor.
CONCLUSIONS: Our data suggest that cardiorespiratory fitness is associated with inhibition in preschoolers. Likewise, our results also suggest that cognitive flexibility is an executive function that is more dependent on changes associated with age at this development stage. These findings are important for supporting initiatives that aimed at stimulating healthy brain development, and promote the improvement of cardiorespiratory fitness at early ages.

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INTRODUCTION

Physical fitness has a positive influence on physical and psychological health in early years and later in life.[1–3] An increasing number of studies have analyzed the impact of physical fitness on cognition in children,[4] particularly on executive functions (EF), which involve high-level cognitive processes, often associated with the prefrontal lobes, that control lower-level processes in the service of goal-directed behavior.[5] Most authors agree that there are three core EF, namely, inhibition, working memory and cognitive flexibility.[6] In general, executive functioning emerges in preschool age and continues to develop across middle childhood and adolescence.[7]

Children who are physically fit have good cognitive performance and brain activation.[8] Cardiorespiratory fitness (CRF) in childhood is associated with better executive performance and differences in function and regional brain structure.[4,9] Recently, motor fitness (e.g., speed/agility) and intellectual maturation have been shown to be related in preschoolers,[10] suggesting a relationship between speed/agility and cognitive development, which is associated with an increased white matter microstructure of the cerebellum and the prefrontal cortex.[11] For muscular fitness, the results are still uncertain in early ages,[12] although some research has found an association with EF and academic achievement.[13]

Several hypotheses have been proposed to explain the positive association between physical fitness and cognitive performance.[14] The neurotrophic hypothesis states that exercise triggers a cascade of biochemical mechanisms that result in increased brain growth factors. More concretely, brain-derived neurotrophic factors (BDNF), insulin-like growth factor 1 and vascular endothelial growth factor are proteins that increase with physical exercise and facilitate the effects of cardiorespiratory exercise on brain structure, function, and cognition.[15] The psychosocial hypothesis advocates that exercise benefits social interactions, mood and physical self-perceptions.[16] Finally, based on the behavioral hypothesis, it has been suggested that physical activity improves coping and self-regulation strategies and sleep volume and quality.[17] Likewise, from exercise and cognition research, a joint neurocognitive and social-cognitive approach has been proposed to emphasize the link between EF and life skills,[18] because EF are essential processes for mental and physical health, academic achievement, and cognitive, social, and psychological development.[6]

Despite the importance of the study of influences on EF at early ages, studies examining the relationship between physical fitness and cognitive development in preschoolers are scarce. Thus, our study aimed to examine the association between the key components of physical fitness (cardiorespiratory, muscular strength and speed/agility) and two core cognition domains

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(inhibition and cognitive flexibility) in a Spanish preschool sample aged 5−6 years.

METHODS

Study design

This was a cross-sectional study analyses of data from baseline measurements of a cluster-randomized trial.[19] The main aim was to assess the effectiveness of a classroom-based physical activity program (MOVI-da10!) in improving cardiorespiratory fitness, adiposity and EF in a preschool sample. The Clinical Research Ethics Committee of the Virgen de la Luz Hospital in Cuenca (Spain) approved the study protocol (reference number: 2016/PI021), which was also approved by the director and board of governors of each school. For data collection, parents gave written consent for their child to participate in the study, and children gave verbal consent when they were asked to collaborate in informative talks held class-by-class. After the data were gathered, the parents were informed by letter of their children's results.

Participants

All children in the last course of preschool education in the nine schools involved in the study were invited to participate. This involved a subsample of 362 preschoolers (age range 57–76 months) who met the following inclusion criteria: (1) in the last course of preschool education; (2) not having any learning disability; (3) not having any type of physical or mental disorder that parents and/or teachers had identified; (4) having the collaboration of a family member to answer questionnaires about free-time family habits; and (5) consent of the parent or guardian for participating in the study.

Study variables

The study variables were measured in September−October 2017 at school by trained investigators in standardized conditions.

Anthropometry. Participants in light clothing were weighed twice with a digital scale (Seca® 861 scales) to the nearest 0.1 kg. Height was measured twice to the nearest 0.1 cm without shoes using a wall-mounted stadiometer (Seca® 222). Body mass index (BMI) was calculated as the weight in kg divided by the square of the height in meters.

Family socioeconomic status. Socioeconomic status (SES) was assessed based on the level of education and occupation of parents, with the former being classified separately as follows:[1] functional illiterates, or no education;[2] primary education (those who did not complete primary education);[3] secondary education (complete primary education, or secondary education, which, in Spain, is compulsory until the age of 16);[4] post-16 education ("Bachillerato" consists of two optional additional years in high school, required if the student wants to attend university; alternatively, vocational education prepares students to work as technicians or in various jobs); and[5] higher education (undergraduate, master's or doctoral degrees). The parents' occupation was classified into five categories:[1] housewife, unemployed;[2] nonqualified worker;[3] self-employed without employees;[4] supervisor/manager or self-employed with less than ten employees; and[5] supervisor/manager or self-employed with ten or more employees. An index of SES (range from 2 to 10) was calculated using both the parents' education and occupation.[20] A higher score indicated higher SES. Due to the small size of the sample in the categories at both ends of the scale, children were classified as low/medium-low (score from 2 to 4), medium (score from 5 to 6), and medium-high/high (score from 7 to 10).

Physical fitness variables. Physical fitness was measured using the PREFIT battery[21] as follows:

– Speed-agility, using the 4×10 shuttle run test in which the children run as fast as possible from the starting line to the other line and return to the starting line (10 m apart), crossing each line with both feet every time. Two attempts were made with an interval of 5 min, and only the best time was used for analysis. Less time represents better results.
– Cardiorespiratory fitness, using the adapted version PREFIT of the Course Navette test (20-min shuttle run test), which has been validated to measure the maximal aerobic capacity in preschoolers.[22] Children are asked to run between two lines 20 m apart while keeping pace with audio signals emitted from a prerecorded audio. The initial speed is 6.5 km h^{-1}, which is increased by 0.5 km h^{-1}. The number of laps completed was recorded as an indicator of his or her cardiorespiratory fitness. Additionally, maximal oxygen intake (VO^2max) was calculated by using the preschool-adapted 20-m shuttle run from PREFIT project.[23]
– Muscle strength was assessed based on upper body and lower explosive body strength. A digital dynamometer with adjustable grip TKK 5401 Grip-DW (Takeya, Tokyo, Japan) was used to measure upper body strength in kg. The test was performed twice with the right hand and twice with the left hand; the mean average of the four measurements was calculated. The standing broad jump test was used for the lower limb explosive strength assessment. From a starting position immediately behind a line, the preschoolers jump horizontally to achieve maximum distance. The best of three attempts was recorded in centimeters.

Executive functions variables. Inhibition and cognitive flexibility were measured using the NIH tool box.[24] All measurements were performed using the digital format test (iPad app), which was administered to the children individually and in a quiet room.

Inhibition was measured using an adapted version of the Eriksen Flanker Task.[24] Participants were required to indicate the left−right orientation of a centrally presented stimulus while inhibiting attention to the potentially incongruent stimuli surrounding it. In some trials, the orientation of the flanking stimuli is congruent with the orientation of the central stimulus (> > > > > or < < < < <), and in other trials, such orientation is incongruent (> > < > > or < < > < <). The task included four practice trials (two congruent and two incongruent sets of arrows) and preschoolers had to get at least three practice trials correctly. If they did not meet this criterion, they received up to three series of four practice trials, and if they still failed to meet criterion, the test was concluded. Three participants were excluded from the study due to this criterion. A total score index was calculated using a two-vector method that incorporated both accuracy and reaction time, for participants who maintained a high level of accuracy (>80%), as follows: ($0.25 \times$ number of 100 correct responses) + 5 – LOG10 [(congruent reaction time + incongruent reaction time/2)]. For children scoring <80%, a total score considering accuracy was calculated.[25]

Cognitive flexibility was measured using the Dimensional Change Card Sort test.[24] This tool presented a stimulus by "color" or "shape", and participants were asked to adapt their response according to the relevant dimension. Participants were required to get three out of four practice trials correct, and if they failed, the four practice trials were repeated up to three times. Once they met this criterion, they received a comparable series of practice trials for the other dimension. Preschoolers who met criterion for each dimension proceeded to the test trials. Four participants were excluded from the study due to this criterion. A total score index was calculated using a two-vector method that incorporated both accuracy and reaction time, for participants who maintained a high level of accuracy (>80%) as follows: ($0.167 \times$ number of correct responses) + 5 – LOG10 [(congruent reaction time + incongruent reaction

Table 1. Physical fitness levels of participants according to Spanish reference standards for preschoolers (PREFIT).[26]

Fitness variables	Boys				Girls			
	P10	P25	P75	P95	P10	P25	P75	P95
CRF: 20mSRT (laps)	11	15	29	41	11	15	29	44
Standing long jump (cm)	57	69	93	111	56	69	93	114
Dinamometry: Handgrip (kg)	5	6	9	11	6	7	9	11
Speed/agility: 4×10 m (s)[a]	14	15	17	19	14	15	17	18

P10: 10th percentile; other percentiles are abbreviated accordingly.
CRF cardiorespiratory fitness.
[a]Lower values indicate better performance.

time/2)]. For children scoring <80%, a total score considering accuracy was performed.[25]

In short, the children excluded in the executive tests were four, with overlap between the inhibition and cognitive flexibility tests for three participants.

Statistical analysis

First, means (SDs) and percentages were calculated to describe the characteristics of the study sample. Second, a *t* test for independent samples was used to test for sex differences on continuous variables, and a chi-square test was used for nominal variables. Third, to examine the association between physical fitness and EF variables, partial correlation coefficients were estimated, with adjustments made for BMI and family socioeconomic status. Fourth, age- and sex-specific physical fitness relative position (percentile, P) was calculated according to Spanish reference standards for preschoolers.[26] Considering these relative positions, children's fitness levels were categorized as follows: low ($<P_{25}$), medium ($P_{25}-P_{75}$), and high ($>P_{75}$). Table 1 summarizes these data. Then, analysis of covariance (ANCOVA) was used to test differences in the mean score of EF by categories of physical fitness, with adjustments made for BMI and SES. Post-hoc pairwise comparisons were tested using the Bonferroni correction for multiple comparisons. Finally, linear regression models were conducted to determine the relevant predictors (age, BMI, SES and CRF) of executive functioning. For all statistical analyses, we used IBM SPSS Statistics 24 (SPSS, Inc., Chicago, IL). The criterion for statistical significance was $p \leq 0.05$.

RESULTS

Descriptive results

A total of 406 preschoolers were invited to participate in the study; of these preschoolers, 362 (183 girls) agreed to participate. No differences in sex, age, or family SES were found between those who participated and those who did not. A total of 50 (13.8%) participants were immigrants or children of immigrants. The sample characteristics are summarized in Table 2, which showed that boys had higher mean values in height, standing long jump, dynamometry, and speed/agility, than girls ($p < 0.05$), whereas girls had higher mean values in BMI ($p = 0.04$). There were no mean differences by sex in performance EF variables.

Association between physical fitness and cognition domain variables

After adjustments were made for confounders (BMI and SES), partial correlation coefficients among CRF, standing long jump, dynamometry, and speed/agility with inhibition and cognitive flexibility variables (Table 3) showed the following: inhibition total score was positively related to CRF ($r = 0.23$, $p < 0.001$) and age was associated with cognitive flexibility total score ($r = 0.15$, $p = 0.008$). No statistically significant correlations were found for the rest of the study variables.

Mean differences of cognition domains by physical fitness categories

Using the inhibition and cognitive flexibility total scores as dependent variables and physical fitness variables as fixed factors (CRF, standing long jump, dynamometry, and speed/agility), after adjustments were made for BMI and family SES, ANCOVA models (Table 4) showed that the mean score in inhibition was significantly better in preschoolers with higher CRF ($p = 0.02$). According to the Bonferroni test, these differences were found for low/high CRF categories ($p = 0.04$). The associations between inhibition, standing long jump, dynamometry, and speed/agility were not found. Regarding cognitive flexibility, no significant results were found.

Linear regression model on executive functions

Multiple linear regression models on executive functions were conducted with age, BMI, family socioeconomic status and CRF as predictor variables (Table 5). The results showed that CRF was a significant predictor of inhibition ($\beta = 0.52$, $p < 0.001$), but for cognitive flexibility, age was the only significant predictor ($\beta = 0.14$, $p = 0.01$).

DISCUSSION

The findings of this study suggest that, after adjustments are made for BMI and family socioeconomic status, preschoolers in higher cardiorespiratory categories have better inhibitory control than do their peers with lower fitness levels. However, no association was found between standing long jump, dynamometry, speed/agility and inhibition or between physical fitness components and cognitive flexibility. Furthermore, our study shows that CRF was a significant predictor of inhibition, but for cognitive flexibility, age was the only significant predictor.

Although a recent review provides some evidence of the relationship between physical activity and CRF and different cognitive domains and academic achievement in schoolchildren,[4] the number of studies focused on these relationships in preschoolers is low. In our study, all the analyses showed that CRF was a significant predictor of inhibition performance, even after adjustments were made for BMI and SES. In this age group, aerobic capacity seems to be related to improvements in spatial working memory and attention.[27] More recently, it has been reported that fitness and intellectual maturity are associated with younger ages.[10] As in our study, when cognitive performance has been compared according to fitness categories, children with higher levels of CRF display significantly better cognitive and academic performance, as well as improved brain functioning and structure.[4,28] Among the most plausible hypotheses for explaining this finding is that CRF promotes angiogenesis in the motor cortex and increases blood flow, thus improving brain vascularization, which could positively influence cognition.[28]

Previous studies have indicated that muscular fitness has health benefits for children, including decreased adiposity and cardiometabolic risk,[12] which have been associated with enhanced cognitive control, mainly with working memory.[16] While the benefits of muscular strength on executive functioning have been described in older adults through increased concentrations of insulin-like growth factor I, which stimulate neuronal growth and improves executive functioning,[29] the results are not conclusive in children, and no specific data have been found for inhibition at preschool age. Our data did not show differences based on muscular strength categories. Thus, to continue exploring this fitness domain is necessary because it has been suggested that skeletal muscle functions as an endocrine organ that influences

Table 2. Characteristics of the study sample by sex.

	Total ($n = 362$)	Boys ($n = 179$)	Girls ($n = 183$)	p for difference
Variables				
Age (months)	63.41 (3.52)	57.03 (3.54)	63.49 (3.51)	0.66
Anthropometric, mean (SD)				
Height (cm)	111.26 (6.13)	112.02 (4.88)	110.51 (7.08)	0.02
Weight (kg)	19.24 (3.51)	19.19 (3.28)	19.29 (3.73)	0.77
BMI (kg/m^2)	15.58 (3.39)	15.21 (1.86)	15.93 (4.38)	0.04
Physical fitness, mean (SD)				
Standing long jump (cm)	76.52 (18.55)	81.60 (20.54)	71.51 (14.78)	<0.001
Dynamometry (kg)	4.35 (2.83)	4.85 (2.81)	3.87 (2.78)	<0.001
Speed/agility (shuttle run 4 × 10 m)[a]	15.87 (1.48)	15.58 (1.54)	16.15 (1.37)	<0.001
CRF: 20-m shuttle run (laps)	24 (12.50)	24.79 (13.68)	23.22 (11.21)	0.23
VO^{2}max	47.92 (3.57)	48.08 (3.78)	47.77 (3.36)	0.40
Family socioeconomic status, n (%)				0.38
Lower	134 (39.6)	60 (36.4)	74 (42.8)	
Middle	127 (37.6)	63 (38.2)	64 (37)	
Upper	77 (22.8)	42 (25.5)	35 (20.2)	
Executive functions, mean (SD)				
Inhibition (FT)				
Total score[b]	5.26 (6.09)	5.47 (8.42)	5.04 (1.80)	0.52
Accuracy	33.24 (10.22)	32.51 (10.48)	33.98 (9.94)	0.18
RT congruent	1.38 (0.42)	1.39 (0.44)	1.38 (0.39)	0.80
RT incongruent	1.59 (0.47)	1.60 (0.49)	1.58 (0.45)	0.65
Cognitive flexibility (DCST)				
Total score[c]	2.98 (2.07)	3.02 (2.03)	2.94 (2.12)	0.72
Accuracy	21.48 (13.58)	21.75 (13.36)	21.21 (13.84)	0.71
RT switch	1.62 (0.42)	1.65 (0.42)	1.60 (0.42)	0.46
RT nonswitch	1.52 (0.40)	1.54 (0.41)	1.50 (0.39)	0.49

The differences between boys and girls were calculated using the independent samples *t* test, except for the family socioeconomic status that was analyzed using the χ^2 test.
BMI body mass index, *CRF* cardiorespiratory fitness, *VO^{2}max* maximal oxygen intake, *FT* Flanker Task, *RT* reaction time, *DCST* Dimensional Change Card Sort Test.
[a]Lower values indicate better performance.
[b]Total score was calculated using a two-vector method that incorporates both accuracy and reaction time: Total score = (0.25 × number correct responses) + 5 – LOG_{10} [(reaction time congruent + reaction time incongruent / 2)]. Range 0–10.
[c]Total score was calculated using a two-vector method that incorporates both accuracy and reaction time: Total score = (0.167 × number correct responses) + 5 – LOG10 [(reaction time congruent + reaction time incongruent / 2)]. Range 0–10.

Table 3. Partial correlation coefficients among physical fitness and cognition domains variables, controlling for body mass index and socioeconomic status.

	Age in months	CRF	Standing long jump	Dynamometry	Speed/ agility
Inhibition					
Total score	0.01	0.23**	0.08	0.10	−0.07
Cognitive flexibility					
Total score	0.15**	0.06	0.05	0.05	−0.02

CRF cardiorespiratory fitness.
*$p \leq 0.01$; **$p \leq 0.001$.

brain metabolism by releasing, through muscle contractions, peptides and cytokines, it is plausible that children with greater muscular fitness could have better brain metabolism.[30] Importantly, since aerobic and muscular fitness are closely related, estimating the independent contribution of each dimension of physical fitness on cognition improvements seems to be a task that remains unfinished. Similarly, the relationship between speed/agility and cognition needs to be clarified, since whereas some cross-sectional studies have reported that both variables are associated,[10,27] others did not find any relation between them.[30] Some methodological weaknesses might be behind these inconclusive results, such as the age-related and developmentally related lack of sensitivity of the tests used to assess both cognitive and motor skills (e.g., speed/agility), the use of self-report data, the differential impact on cognition of the exercises used to assess motor skills and, finally, the lack of control for some confounders (e.g., age, sex, SES or anthropometry variables) in the statistical analyses.[31]

Because cognitive flexibility could be considered the most complex dimension of the core EF and because each skill emerges at different points in time and has its own developmental trajectory,[32] it is not surprising that in preschool children, age, as the variable that is more closely related to brain development, proves to be the only predictor of cognitive flexibility in our study. In this sense, some studies have reported that during late childhood, inhibition is more closely associated with CRF than is

Table 4. Analysis of covariance testing mean differences in cognition domains scores by physical fitness categories, controlling for body mass index and family socioeconomic status.

	Physical fitness categories			*p* for difference	Bonferroni Test		
	Low	Medium	High		Low/Medium *p*	Medium/High *p*	Low/High *p*
CRF							
Inhibition total score	4.60 (0.69)	4.68 (0.53)	6.69 (0.63)	0.02	1.00	0.07	0.04
Cognitive flexibility total score	2.89 (0.23)	2.97 (0.18)	3.21 (0.21)	0.54	1.00	1.00	0.91
Standing long jump							
Inhibition total score	4.65 (0.61)	5.18 (0.51)	6.53 (0.78)	0.16	1.00	0.44	0.17
Cognitive flexibility total score	2.82 (0.21)	3.16 (0.17)	3.06 (0.26)	0.45	0.63	1.00	1.00
Dynamometry							
Inhibition total score	4.96 (0.41)	6.18 (0.69)	4.38 (2.83)	0.29	0.39	1.00	1.00
Cognitive flexibility total score	3.05 (0.14)	2.98 (0.23)	2.19 (0.94)	0.65	1.00	1.00	1.00
Speed/agility[a]							
Inhibition total score	6.11 (0.62)	5.04 (0.50)	4.53 (0.78)	0.24	1.00	0.55	0.35
Cognitive flexibility total score	2.88 (2.21)	3.11 (0.17)	3.02 (0.26)	0.70	1.00	1.00	1.00

Data are presented as marginal estimated mean ± SE.
CRF cardiorespiratory fitness.
[a]Lower values indicate better performance.

Table 5. Linear regression models to determine the relevant predictors (age, body mass index, family socioeconomic status and cardiorespiratory fitness) of executive functioning.

Dependent variable	Predictors	β	t	p	R^2	Adjusted R^2
Inhibition total score	Age (months)	−0.05	−0.85	0.39	0.08	0.07
	Body mass index	−0.02	−0.41	0.68		
	Family socioeconomic status	0.07	1.24	0.21		
	Cardiorespiratory fitness	0.52	4.49	**<0.001**		
Cognitive flexibility total score	Age (months)	0.14	2.42	**0.01**	0.02	0.01
	Body mass index	0.01	2.27	0.78		
	Family socioeconomic status	−0.02	−0.43	0.66		
	Cardiorespiratory fitness	0.06	0.50	0.61		

The data are presented as standardized regression coefficient.
The *p* values in bold indicate statistical significance for the corresponding predictor in the model with the cognition.

cognitive flexibility, but these differences are not maintained during adolescence.[9,31] Accordingly, the different influence of the age-dependent maturational changes in the prefrontal cortex and cortical and subcortical structures, including parietal regions and basal ganglia,[33] have been described with respect to cognition domains, whereby in our study, only age was a significant predictor of cognitive flexibility.

Several limitations should be acknowledged in this study. First, the cross-sectional nature of the study prevents us from making cause−effect inferences. Longitudinal data would permit a deeper analysis of the fitness and EF variables providing complementary information across preschool years. Second, the introduction section presents three hypotheses as plausible explanations for the link between fitness and cognitive performance. However, the current study was not designed to test some of them, which should be considered in order to explore their specific predictions. In this same line, because the correlations between physical fitness and executive functioning were small, perhaps psychosocial or behavioral factors could affect these relationships. Additional physical fitness measures and psychosocial variables are needed in future studies. Third, approximately 1% of participants were excluded from the study because they did not meet the criteria of the cognitive tests, although we believe that these data should not have significantly affected our results. In this regard, the inherent difficulties in the measurement of EF in preschoolers is why some authors recommend including several tasks for each EF to obtain a more reliable measure of executive functioning.[34] Finally, this study lacked working memory assessment, a task has been suggested[35] to be too difficult to perform in school settings in preschoolers. In order to solve these difficulties, Missing Scan Task has been demonstrated to be a valid tool for assessing working memory in preschool children as young as 3 years of age.[36]

Conclusion

According to our results, CRF seem to be physical fitness dimension related to the ability to inhibit or control impulsive (or automatic) responses and create reactions by using attention and reasoning in preschoolers. From our point of view, these findings are important for supporting initiatives that aimed at stimulating healthy brain development, and promote the improvement of CRF at early ages. Thus, compliance with physical activity recommendations for preschool children[37,38] could be important in not only protecting their physical health but also promoting adequate brain maturation. To conclude, high-quality intervention studies that indisputably establish the potentially causal relationship between each physical fitness dimension and cognitive abilities are needed because our conclusions are uniquely endorsed by our data and those from a few studies conducted in preschool children, along with expert recommendations.[39]

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AUTHOR CONTRIBUTIONS

M.N.-L. and M.S.-L. designed the study. V.M.-V. was the principal investigator and obtained the funding. V.M.-V. and M.S.-L. gave statistical and epidemiological support. M.N.-L. wrote the article with the support of C.A.-B. and M.S.-L. C.A.-B., M.E.V.-A, E.J.-L. conducted the study. All authors established the methods and questionnaires, provided comments on the drafts, and have read and approved the final version.

ADDITIONAL INFORMATION

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