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Original research

The effect of active learning on cognitive performance and physical fitness in preschool children: the role of exercise intensity

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ABSTRACT

Objectives: To analyze the effects of different PA intensities during active learning on cognitive performance and physical fitness in preschool children.
Design: Cluster randomized controlled trial.
Methods: Four classrooms (n = 99 children aged 3–6 years) were randomly allocated to two intervention groups that performed either light PA (LPA, n = 26) or moderate-to-vigorous PA (MVPA, n = 25) during foreign language (English) lessons, or to a control group (n = 48) that maintained their usual sedentary lessons. The intervention consisted of two 45-min lessons per week and was performed over a 10-week period. Children's PA levels and intensity during sessions were assessed through accelerometry. Primary outcomes included the retention of foreign language vocabulary (free- and cued-recall tests), cognitive performance (BENCI battery), and physical fitness (PREFIT battery).
Results: Both LPA and particularly MVPA groups resulted in greater total PA levels and intensity compared with the control group ($p < 0.001$) and provided significantly larger benefits in the free-recall test and verbal memory (all $p < 0.05$ compared to the control group). Additionally, MVPA group provided larger benefits in the free- and cued-recall tests, speed agility and cardiorespiratory fitness (all $p < 0.05$ compared to LPA).
Conclusions: Physically active learning appears as an effective strategy for enhancing foreign language vocabulary, cognitive performance, and physical fitness in preschool children. Increasing PA intensity seems to maximize these benefits.

Practical implications

- Physically active learning interventions have proven beneficial for improving cognitive performance and overall academic achievement in primary school children and adolescents. However, their benefits on preschool children, as well as whether these benefits could depend on the intensity of these interventions, remain unclear.
- Physically active learning appears as an effective strategy for improving foreign language vocabulary, cognitive performance and physical fitness in preschool children.
- Increasing physical activity intensity seems to maximize benefits on foreign language vocabulary, cognitive performance and physical fitness in preschool children.

1. Introduction

Childhood physical inactivity has emerged as a global concern, with only one in five children and adolescents meeting current international guidelines for physical activity (PA).[1] Beyond the well-established

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cardiovascular health risks associated with physical inactivity,[2] evidence indicates that low PA levels can also adversely affect cognitive performance and academic achievement.[3] Under this context, efforts have been directed toward increasing PA levels among children, with a notable emphasis on promoting PA interventions within the school environment. Schools represent indeed an excellent setting for PA promotion, particularly given that children spend a significant portion of their school time in sedentary activities.[4]

Interventions targeting PA in children have been reported to be effective for the improvement of not only physical fitness and overall cardiovascular health,[1] but also academic achievement and cognitive performance.[3] However, controversy exists on whether these benefits could depend on specific intervention characteristics, such as PA volume or intensity, or integration within academic content.[3,5] Particularly, whether a higher PA intensity yields greater benefits on cognitive performance remains unclear. While a dose–response association between PA intensity and cognitive performance has been reported in older adults,[6] scarce evidence exists in children or adolescents.[7,8] Following Schmidt et al.,[9] no improvements were found in academic achievement in children aged 8–10 years following a school-based PA intervention, which might be due to the low PA intensity employed. Indeed, preliminary evidence in adolescents suggests that higher PA intensity during physical education lessons may provide greater benefits on cognitive performance and academic achievement.[10]

This knowledge gap underscores the need to investigate the role of PA intensity on cognitive function and physical fitness, particularly during early childhood. Under this context, the present study aimed to compare the effects of two different intensities of physically active learning interventions on foreign language vocabulary acquisition, overall cognitive performance, and physical fitness in preschool children.

2. Methods

2.1. Study design

The present study (The English Learners Fit [ELFIT] study) was a 10-week single-center, single-blinded, cluster randomized controlled trial conducted from January 2023 to March 2023. This trial follows the Consolidated Standards of Reporting Trials (CONSORT)[11] guidelines.

The ELFIT trial was performed during the lessons allocated to English as a foreign language (2 sessions of 45 min per week). Participants pertained to four different classrooms within the same school, and these classrooms were randomly assigned to either a control group or two intervention groups. The control group (2 classrooms) maintained the usual sedentary lessons in the classroom, whereas the intervention groups engaged in either light (LPA, 1 class) or moderate-to-vigorous PA (MVPA, 1 class) during these lessons (Fig. 1). Due to the nature of the experiment, blinding students and teachers was not possible. However, assessors and statisticians responsible for data analysis were kept unaware of the group assignments. Principals, teachers, and parents provided written informed consent before the study. Ethical approval was obtained from the Research Ethics Committee at Universidad Complutense de Madrid (CE_20211118-16_SAL).

This randomization approach at classroom level aimed to minimize the potential for contamination between pupils within the same classroom. Randomization was completed at classroom levels since classroom groups were already set within the school organization, and it was conducted using computer-generated random numbers by an investigator who was not involved with the participants. The resulting allocation sequence was securely stored within sealed envelopes by the project management team, ensuring confidentiality until the completion of data analyses.

2.2. Participants

Participants were recruited from the same school at Madrid (Spain). The ELFIT study was offered to all class teachers in the school. Four class teachers declared interest in the study to be assessed for eligibility, and their students were included as a convenience sample (Fig. 1). To be eligible for the study, children had to be between 3 and 6 years old, able to perform the PA interventions, and able to complete the cognitive performance tests. Exclusion criteria encompassed children with pathologies or conditions contraindicating PA, such as musculoskeletal injuries, cardiorespiratory disorders, and other mild disorders. Additionally, those

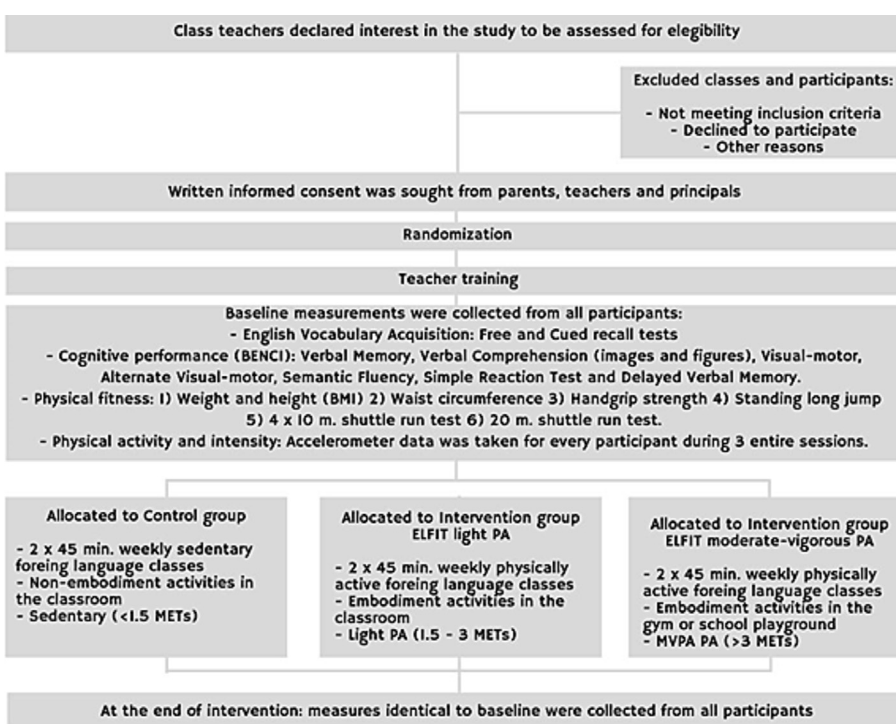

Fig. 1. Study design.

with diagnosed developmental or cognitive difficulties (e.g., attention-deficit hyperactivity disorder) were excluded. Children attending to English lessons as an extracurricular activity or having relatives who speak English as their native language were also excluded. Despite these criteria, in agreement with their teachers, all children in the participating classrooms were encouraged to join the activities as a part of their academic tasks, ensuring that no child felt excluded from the study.

2.3. Intervention

All lessons were conducted by the respective classroom teachers of each group, who were trained by an experienced researcher. At the beginning of the intervention, in the initial session, all words were presented to the children in both their native language (Spanish) and in English to ensure that they understood their meaning. Children were then informed that they would participate in a memory game and were instructed to attentively listen to the teachers' guidance. They were further instructed to repeat the words in English after the teacher, and in the case of the MVPA and LPA groups, engage in a specific activity at the end of each word (see below for more details).

At the beginning of each session, the daily vocabulary words were introduced one at a time, with each word displayed for 1 min until the entire set was covered. The words were presented both auditory and visually in English language. Following the presentation by the teacher, children were required to repeat each word. In total, 24 words were taught, including: *body*, *head*, *legs*, *arms*, *hands*, *feet*, *crocodile*, *giraffe*, *monkey*, *parrot*, *penguin*, *tiger*, *spider*, *duck*, *fox*, *frog*, *mouse*, *rabbit*, *snake*, *down*, *up*, *bike*, *plane*, and *train*.

Subsequently, students were taught the English words using a different approach depending on their assigned group. In the control group, children verbally repeated the words while remaining seated, ensuring a target intensity of <1.5 metabolic equivalent of tasks (METs). During the LPA intervention, which was also conducted in the classroom, children not only repeated the words but also physically enacted the associated actions to facilitate learning, targeting a low intensity (1.5–3 METs). This involved a variety of light activities such as walking or dancing. For example, when learning the word “bird”, children walked around the classroom and mimicked the motion of flying with their arms. Conversely, children in the MVPA group conducted their lessons in the gym or playground, engaging in physically active exercises to reinforce word learning, but in this case, targeting a moderate-to-high intensity (>3 METs). This involved performing high-intensity activities such as running, relay racing, obstacle courses, and active play. As an illustration, for the word “bird”, children ran in the gym while simulating the action of flying with their arms. In addition, in both intervention groups (LPA and MVPA) the children walked continuously around the classroom or playground while listening to the teachers' instructions.

Exercises for the MVPA and LPA groups were derived and adapted from various sources, including 12 and technology/websites (i.e., http://www.oxfordpremium.oupe.es). Permission from the writers (personal communication) to use and change these practices was obtained. Specific characteristics of ELFIT activities are outlined in Table 1.

2.4. Outcomes

Assessments were administered in the classroom (cognitive outcomes) and the gym (fitness outcomes) by an external examiner with the assistance of classroom teachers both before (baseline) and at the end of the 10-week intervention (post-intervention).

2.4.1. Foreign language

The assessment of children's ability to retain English words was performed individually through free-recall and cued-recall tests adapted for preschoolers.[9,13,14] The assessment encompassed the 24 words taught during the learning phase. However, whereas in the free-recall test participants were instructed to recall as many words as possible without help, in the cued-recall test they were prompted with pictures. Words recalled were also considered correct when minor spelling errors or singular-plural substitutions occurred. The total number of words remembered in the free-recall test as well as the number of correct words in the cued-recall test were registered.

2.4.2. Cognitive performance

Cognitive performance was assessed through the BENCI (Computerized Battery for Neuropsychological Evaluation of Children), which includes the basic neuropsychological domains required to conduct a complete neuropsychological assessment.[15] The battery was completed individually by each participant using a tablet (iPad 6 9.7″ screen, Apple, CA) under the supervision of an examiner. As proposed elsewhere,[16] we focused on the following tests:

Test 1. Verbal memory. Participants listened to the same series of words three times and, at the end of each sequence, they had to repeat aloud all the words they remembered. The number of correct answers was registered by the examiner. Number of words: 6.
Test 2. Verbal comprehension (images). A set of pictures from a given category (e.g., animals) was shown and participants were instructed to select a picture that fulfilled the indicated conditions (type of animal, position, activity it can perform, and/or color; e.g., “Touch the frog next to the dog”). The number of correct answers was automatically registered. Number of instructions: 8.
Test 3. Verbal comprehension (figures). Similar to the previous test, but with pictures of geometric figures (circles, triangles, and squares of different sizes and colors; e.g., “Touch a small blue circle”). The number of correct answers was automatically registered. Number of instructions: 8.
Test 4. Visuomotor. Participants touched, in an increasing order or according to a given sequence, the numbers or elements that appeared randomly on the screen. The number of correct answers and completion time (in secs) were automatically registered. Number of elements: 10.
Test 5. Alternate visuomotor. Participants pressed, in alternating and ascending order, the numbers of two different series that were displayed randomly on the screen. The number of correct answers and completion time (in secs) was automatically registered. Number of elements: 10.

Table 1
Interventions' characteristics.

Activity characteristics	Control	LPA	MVPA
Place	Classroom	Classroom	Gym or playground
Embodiment activities	No	Yes	Yes
PA intensity target	Sedentary (<1.5 METs)	Light (1.5–3 METs)	Moderate-vigorous (>3 METs)
Resources	Smartboard Flashcards	Smartboard Flashcards	Flashcards Gym equipment (cones, balls, etc.)

Abbreviations: LPA, light physical activity group; METs, metabolic equivalent of tasks; MVPA, moderate-to-vigorous physical activity group; PA, physical activity.

Test 6. Semantic fluency. Participants listened to a semantic category (colors or animals) and had to tell aloud all the items they knew from that category. The number of correct answers was registered by the examiner. Time: 30 s.
Test 7. Simple reaction time test. Participants touched the screen as fast as possible when a cross was displayed on the screen (+). Reaction time (in ms) was automatically registered.
Test 8. Verbal memory (delayed and recognition trails). In the delayed test, 20 min after the end of the verbal memory test, participants had to repeat aloud all the words they remembered from the list that was presented in that test. In the recognition test, immediately after the previous test, participants listened to a group of words, half of which belonged to the list presented in the verbal memory test and had to state whether each of them was on that list. The number of correct answers was registered by the examiner. Number of words: 6.

2.4.3. Physical fitness

The PREFIT battery was used to assess participants' anthropometry, muscle strength, speed-agility and cardiorespiratory fitness, as explained elsewhere.[17]

2.4.3.1. Anthropometry. Body mass and height were measured to the nearest 0.1 kg and 1 mm, respectively, following standard procedures using an electronic scale and a stadiometer (Model 600KL, Health O Meter Professional, McCook IL, 1992), and body mass index (BMI) was then computed. Waist circumference was measured to the nearest 0.1 cm using an ergonomic non-elastic measuring tape (Model 67020, Gulick II tape measure, Morgan Hill CA, 2010). Two measurements were performed for each variable and the mean of both was retained for the analyses.

2.4.3.2. Muscle strength. Handgrip strength was measured using a handgrip dynamometer (Model EH101, Camry Digital, Zhongshan, 2014), maintaining an optimum grip-span of 4.0 cm, as recommended by Sanchez-Delgado et al.[18] Participants were instructed to hold the dynamometer for 2–5 s while squeezing steadily and consistently. Two trials were performed with each hand, and the best result (in kg) was used for analyses. Brief rest intervals were allowed between tests.

Lower-limb strength was assessed through a standing long jump performed from a standing start and with feet together. The distance (in cm) from the takeoff line to the back of the heels was measured. If the child fell backwards or made contact with the mat using another part of the body, a further attempt was allowed. Two trials were conducted, and the best result was used for analyses.

2.4.3.3. Speed-agility. Speed-agility was measured through the 4 × 10-m shuttle run test. Two parallel lines were drawn 10 m apart on the ground, with an evaluator positioned on each line. After giving the starting signal, the child sprinted to the other line as fast as possible, touched the evaluator's hand, and returned to the starting line, ensuring both lines were crossed with both feet. Then, the child sprinted back to the opposite line again, touched the evaluator's hand, and returned swiftly to the starting line. Two trials were conducted, and the fastest time was used for analyses.

2.4.3.4. Cardiorespiratory fitness. In the 20-m shuttle run test, children ran between two lines set 20 m apart, paced by the evaluator who ran alongside them. This test was adapted for preschoolers.[19] The initial speed was 6.5 km/h, increasing by 0.5 km/h every minute. The evaluation continued until the student failed to hit the finish line with the audio signal on two separate occasions. Otherwise, the test finished when the child stopped exercising due to exhaustion. The test was completed once. After the child stopped, the last completed lap was retained for analyses.

2.4.4. Physical activity

Tri-axial wrist-worn accelerometers (ActiGraph wGT3X-BT, ActiGraph, FL) were used to measure participants' PA levels and intensity during three lessons for each participant at three time points: during weeks 5, 6 and 7 throughout the intervention. The accelerometers were positioned on the right hip, with a sampling frequency of 90 Hz and using five-second epochs.[20,21] Cutoff points were set at: sedentary <820 counts per minute (cpm), light 820–3907 cpm, moderate 3908–6111 cpm and vigorous >6112 cpm.[20] The average minutes per session spent on MVPA, LPA, or sedentary time, along with the average counts per session, were calculated using data from each participant in a valid session. A valid session was defined as children wearing accelerometers for the whole session.[21] Accelerometer data was downloaded and processed using ActiLife 6 Software (ActiGraph).

2.5. Statistical analyses

Data normality and homoscedasticity were checked. The effects of the intervention on study outcomes were assessed using a mixed analysis of covariance (ANCOVA), setting group as a between-subject factor, and the change from baseline to post-intervention as the dependent variable. Covariates included age, sex, socioeconomic status (registered using the questionnaire included in the BENCI battery[15]), classroom, baseline values of the analyzed outcome, as well as PA levels outside of the intervention (registered using parents' questionnaire[22]). Baseline descriptive variables that differed between groups were also included as covariates (age, height and weight). In addition, the potential impact of physical fitness (muscle strength, speed agility and cardiorespiratory fitness, most reliable variables in the PREFIT battery[17]) was included as a covariate only when the outcomes were cognitive-related. Post-hoc pairwise comparisons (Bonferroni) were performed when a significant effect was found. Descriptive statistics are presented as mean ± SD. Results are presented as change from baseline unless otherwise stated, and are presented along with effect sizes (Cohen's *d*, obtained from dividing the adjusted estimated marginal means by the pooled standard deviation). Mediation analyses were performed to examine whether the association between the interventions (independent variable) and the changes in cognitive outcomes (dependent variable) were mediated by the changes in physical fitness outcomes (specifically handgrip strength or CRF, which are the fitness measures with the strongest evidence on their association with cognitive function in children[23]). Analyses were performed using the PROCESS macro for SPSS. All analyses were carried out with the statistical package SPSS 29, IBM, Armonk, NY with the significance level set at $p < 0.05$.

3. Results

A flow diagram of study participants is presented in Supplementary Fig. 1. From a total of 99 children (58 girls and 41 boys), 48 were allocated to the control group, 26 to the LPA group and 25 to the MVPA group (descriptive characteristics are shown in Table 2). Groups were similar regarding most descriptive variables (sex, socioeconomic status, anthropometrical variables and PA levels outside of the intervention) with the exception of age ($p < 0.001$), height ($p < 0.001$) and weight ($p = 0.015$). Thus, all these variables were included as covariates in statistical analyses — in addition to sex, classroom, baseline values of the analyzed outcome and PA levels. In addition, the potential impact of physical fitness (muscle strength, speed agility and cardiorespiratory fitness, most reliable variables in the PREFIT battery[17]) was included as a covariate only when the outcomes were cognitive-related. No adverse events were reported during the study.

The effects of the interventions on cognitive and physical fitness outcomes are reported in Tables 3 and 4, respectively (unadjusted results are shown in Supplementary Tables 1 and 2). Both LPA and MVPA provided significant benefits compared with the control group in foreign language, as reflected by greater improvements in the free-recall test

Table 2
Descriptive characteristics of participants at baseline by group.

Variables	Control	LPA	MVPA	p-Value
Age (years)	5.0 ± 0.5	4.6 ± 0.2[a]	5.5 ± 0.3[bc]	<0.001
Sex (girls, %)	62.5 %	53.8 %	56.0 %	0.742
Socioeconomic status (a.u.)	2.98 ± 0.75	3.12 ± 0.76	3.12 ± 0.72	0.658
Height (cm)	111 ± 5.7	105 ± 4.9[a]	114 ± 5.3[c]	<0.001
Weight (kg)	19.9 ± 2.6	18.8 ± 3.5	21.3 ± 3.1[c]	0.015
Waist (cm)	54.4 ± 2.5	54.1 ± 4.1	53.6 ± 2.3	0.568
BMI (kg/m^2)	16.0 ± 1.1	16.8 ± 1.7	16.3 ± 1.4	0.116
PA levels (a.u.)	12.8 ± 2.2	12.0 ± 1.9	13.0 ± 2.5	0.281

Abbreviations: BMI, body mass index; LPA, light physical activity group; MVPA, moderate-to-vigorous physical activity group.
Data are shown as mean ± SD or %. Significant differences are indicated by respective letters (a = Control-LPA; b = Control-MVPA; c = LPA-MVPA).

($p < 0.001$), (Table 3). Both intervention groups also resulted in greater benefits in cognitive performance compared to the control group, as reflected by greater benefits on verbal memory ($p = 0.019$ and $p = 0.003$, *respectively*) (Table 3). In addition, LPA — but not MVPA — induced significant benefits compared to the control group in verbal comprehension images ($p = 0.025$) and figures ($p = 0.016$), whereas MVPA — but not LPA — provided significant benefits compared to the control group in the cued recall test ($p < 0.001$), semantic fluency ($p = 0.005$), verbal memory recognition ($p = 0.011$) and several physical fitness parameters, including muscle strength ($p = 0.021$), speed-agility ($p = 0.004$), and cardiorespiratory fitness ($p < 0.001$). Of note, MVPA resulted in significantly greater benefits than LPA in the free-recall test ($p = 0.010$), the cued-recall test ($p = 0.001$), speed-agility ($p = 0.038$) and cardiorespiratory fitness ($p = 0.004$). No significant between-group differences were found for the remaining outcomes.

Both LPA and MVPA resulted in significantly higher PA levels and intensity during lessons compared with the control group ($p < 0.001$) (Table 5, unadjusted results shown in Supplementary Table 3). Moreover, MVPA also resulted in higher PA levels and intensity compared with LPA ($p < 0.001$). Mediation analyses revealed that improvements in physical fitness did not significantly mediate the observed improvements in cognitive outcomes (indirect effect p > 0.05 for all cognitive outcomes).

4. Discussion

The present study demonstrates that engaging preschool children in physically active learning leads to enhanced acquisition of foreign language vocabulary and greater improvements in overall cognitive performance compared to their typical sedentary foreign language lessons. Notably, both the LPA and MVPA groups likely benefited from the meaningful connection between the word and the gesture. However, our findings also suggest that, apart from this potential connection, a higher PA intensity during lessons resulted in additional benefits in foreign language vocabulary acquisition and induced greater improvements in speed agility and cardiorespiratory fitness.

Our findings indicate that both LPA and MVPA interventions effectively reduced sedentary time and increased PA levels during lessons, with larger effects observed with the MVPA intervention. These results are particularly meaningful given that children spend a considerable portion of their school time in sedentary activities.[4] Therefore, physically active learning interventions might help decrease sedentary time in schools while simultaneously improving language, cognitive performance, and physical fitness, as supported by our findings. These benefits align with those observed in other physically active learning interventions, highlighting the positive impact of PA in children and adolescents.[3] However, to the best of our knowledge the present study is the first one to confirm such benefits in preschool children. It is worth noting, however, that we found no significant benefits of PA interventions on other cognitive-related outcomes such as visual-motor coordination or reaction time, indicating the need for further research to validate these findings. Although physical fitness has been positively associated with cognitive function in children, and in the present study the MVPA intervention provided the greatest benefits on both physical fitness and cognitive function, our mediation analyses show that physical fitness improvements did not mediate the observed improvements in cognitive outcomes. Future research is therefore needed to determine the mechanisms underlying the observed benefits on cognitive function.

Table 3
Effects of the interventions on cognitive performance.

Cognitive outcomes	Control	LPA	MVPA	p-Value
Free-recall (CA, n)	0.60 ± 0.19 0.500	2.23 ± 0.32[a] 1.858	3.53 ± 0.23[bc] 2941	<0.001
Cued-recall (CA, n)	1.68 ± 0.29 0.984	3.15 ± 0.50 1.845	5.5 ± 0.35[bc] 3.244	<0.001
Verbal comprehension (images) (CA, n)	−0.17 ± 0.14 −0.087	0.75 ± 0.25[a] 0.385	0.20 ± 0.17 0.102	0.020
Verbal comprehension (figures) (CA, n)	−0.24 ± 0.13 −0.147	0.68 ± 0.23[a] 0.419	0.24 ± 0.16 0.147	0.001
Semantic fluency (CA, n)	−0.07 ± 0.15 −0.056	0.61 ± 0.25 0.493	0.68 ± 0.18[b] 0.549	0.005
Verbal memory (CA, n)	0.01 ± 0.06 0.010	0.44 ± 0.11[a] 0.479	0.35 ± 0.08[b] 0.381	0.001
Verbal memory recognition (CA, n)	0.02 ± 0.16 0.014	0.84 ± 0.26 0.616	0.76 ± 0.18[b] 0.557	0.008
Verbal memory delayed (CA, n)	−0.03 ± 0.09 −0.027	0.22 ± 0.16 0.201	−0.05 ± 0.12 −0.045	0.453
Visual-motor (CA, n)	1.25 ± 0.60 0.407	1.89 ± 1.02 0.616	1.35 ± 0.71 0.440	0.899
Visual-motor (CT, s)	1.69 ± 3.22 0.100	−13.63 ± 5.48 −0.809	−2.42 ± 3.78 −0.143	0.133
Alternate visual-motor (CA, n)	−0.07 ± 0.61 −0.023	−0.25 ± 1.29 −0.084	0.15 ± 0.91 0.050	0.963
Alternate visual-motor (CT, s)	7.03 ± 4.65 0.265	16.89 ± 7.89 0.638	11.87 ± 5.52 0.448	0.622
Simple reaction test (RT, ms)	26.92 ± 21.53 0.253	20.72 ± 37.00 0.195	−3.88 ± 25.68 −0.036	0.629

Abbreviations: CA, correct answers; CT, completion time; LPA, light physical activity group; MVPA, moderate-to-vigorous physical activity group; PA, physical activity; RT, reaction time. Results are shown as change from baseline to post-intervention (mean ± SD) and effect size. Analyses were adjusted for age, sex, classroom, socioeconomic status, height, weight, muscle strength, speed-agility, cardiorespiratory fitness and baseline values. Significant differences are indicated by respective letters (a = Control-LPA; b = Control-MVPA; c = LPA-MVPA).

Table 4
Effects of the interventions on physical fitness outcomes.

Physical fitness outcomes	Control	LPA	MVPA	p-Value
Waist circumference (cm)	0.016 ± 0.097 0.006	0.071 ± 0.162 −0.005	−0.101 ± 0.121 −0.005	0.443
BMI (kg/m^2)	0.038 ± 0.084 0.010	−0.039 ± 0.141 −0.018	−0.031 ± 0.101 0.000	0.853
Handgrip strength (kg)	−0.112 ± 0.091 −0.071	0.248 ± 0.153 0.181	0.116 ± 0.110 0.032	0.144
Standing long jump (cm)	−1.608 ± 0.635 −0.095	0.687 ± 1.056 0.045	1.120 ± 0.760[b] 0.060	0.023
4 × 10 shuttle run test (s)	−0.025 ± 0.101 −0.011	−0.018 ± 0.169 −0.023	−0.546 ± 0.121[bc] −0.333	0.002
20-m shuttle run test (laps)	−0.007 ± 0.192 −0.001	0.033 ± 0.320 0.017	1.419 ± 0.229[bc] 0.257	<0.001

Abbreviations: BMI, body mass index; LPA, light physical activity group; MVPA, moderate-to-vigorous physical activity group.
Results are shown as change from baseline to post-intervention (mean ± SD) and effect size. Analyses were adjusted for age, sex, classroom, socioeconomic status, height, weight and baseline values. Significant differences are indicated by respective letters (a = Control-LPA; b = Control-MVPA; c = LPA-MVPA).

While both MVPA and LPA interventions induced consistent benefits on several cognitive outcomes compared to the control group, a significant finding of our study is that MVPA appeared to provide the greatest benefits in foreign language vocabulary, semantic fluency, verbal memory, muscle strength, speed-agility, and cardiorespiratory fitness. Despite evidence of a dose–response association between PA intensity and cognitive performance in older adults,[6] controversy exists in children. Indeed, while a recent systematic review suggested that there is consistent evidence supporting such relationship in children,[8] others have not found such benefits.[7] However, evidence remains limited and inconclusive to date, with only few studies addressing this topic. While some studies have reported significant benefits in cognitive measures among participants in the high-dose PA condition compared to the low-dose PA condition,[24,25] others have not found such benefits.[26] Indeed, in the present study only the LPA group showed improvements in verbal comprehension. Therefore, although our findings overall support a potential dose–response effect (with MVPA inducing larger benefits on outcomes such as free-recall test and verbal memory), further research is warranted to confirm whether increasing PA levels or intensity results in improvements in all cognitive outcomes. It can be hypothesized that in the present study the MVPA intervention was associated with an excessive PA intensity that precluded optimal cognitive processing during the lessons, at least regarding verbal comprehension. Moreover, the different setting (classroom in the case of LPA vs gym setting in the case of MVPA) could also affect participants' arousal state and consequently comprehension levels during the lessons. Further research is however needed on the long-term impacts of LPA and MVPA on these outcomes.

Although the exact mechanisms underlying the influence of PA on cognition and language skills remain unknown, several have been proposed. According to Lubans et al.,[27] these mechanisms can be categorized into three groups: neurobiological, psychosocial, and behavioral. The neurobiological mechanism hypothesis suggests that engaging in PA can enhance cognition and mental health by altering the structure and function of the brain.[28] Additionally, PA has been shown to help prevent obesity in children and adolescents,[29] which is itself linked to impaired cortical development.[30] Furthermore, school-based PA interventions enhance physical fitness,[31] which has been associated with improved cognitive performance.[32] Physical fitness has also been associated with increased cerebral blood flow, further supporting the cognitive benefits of PA.[28] Regular PA promotes the production of neurotrophic factors (e.g., brain-derived neurotrophic factor) and angiogenic factors (e.g., vascular endothelial growth factor [VEGF]), which enhance brain plasticity and cognitive functioning.[30]

In addition, integrating PA into academic content may have unique cognitive benefits, as there is biological evidence supporting the connection between language and action. Research suggests a neural overlap between the mirror neuron system for action and Broca's area, which is involved in speech articulation.[33,34] This aligns with the embodied cognition framework, which emphasizes that language and cognition are deeply rooted in the sensory-motor system. This approach highlights the essential role of the sensory-motor system in language processing and comprehension. Furthermore, neurophysiological studies show that the motor system is not only engaged during the comprehension of concrete language but also plays a role in understanding abstract language.[33] Psychosocial mechanisms can also play a role, as PA can satisfy basic psychological needs for social connection, autonomy, self-acceptance, and purpose in life.[35] Finally, some behavioral mechanisms that are affected by PA, such as improved sleep patterns and self-regulation skills, might also positively affect cognitive outcomes.[25]

A major strength of the present study is that it is, to our knowledge, the first to analyze the effect of physically active learning of two different intensities on the acquisition of foreign language vocabulary, overall cognitive performance, and physical fitness in preschool children. Additionally, the study design and the validity and reliability of all assessment instruments used can also be considered strengths of our work. However, some limitations must be acknowledged, notably the relatively small sample size. Unequal sample size distribution between groups was due to the fact that classroom groups were already set within the school organization. This unequal distribution might have had a potential impact on the study's

Table 5
Physical activity levels and intensity by group.

Activity	Control	n	LPA	n	MVPA	n	p-Value
Sedentary (min)	42.4 ± 0.04	43	0.7 ± 0.06[a]	23	2.1 ± 0.04[bc]	23	<0.001
Light (min)	2.0 ± 0.04	43	43.0 ± 0.08[a]	23	3.5 ± 0.05[bc]	23	<0.001
Moderate-to-vigorous (min)	0.5 ± 0.04	43	1,1 ± 0.07[a]	23	39.3 ± 0.05[bc]	23	<0.001
Total PA (counts)	145.4 ± 18.4	43	2202.0 ± 31.4[a]	23	6792.8 ± 21.5[bc]	23	<0.001

Abbreviations: LPA, light physical activity group; MVPA, moderate-to-vigorous physical activity group; PA, physical activity.
Results are shown as average time spent per 45-min-session on MVPA, LPA, or sedentary time, and average counts (mean ± SD). Analyses were adjusted for age, sex, classroom, socioeconomic status, height, weight, muscle strength, speed-agility and cardiorespiratory fitness. Significant differences are indicated by respective letters (a = Control-LPA; b = Control-MVPA; c = LPA-MVPA).

conclusions. However, statistical methods were employed to minimize bias and ensure robustness in group comparisons. Additionally, due to the nature of the experiment, blinding students and teachers was not feasible, which could introduce potential bias. Further research is also needed to compare the effectiveness of different PA interventions and to examine whether similar effects can be found regardless of participants' characteristics (e.g., socioeconomic status, sex, weight category). Unfortunately, PA levels outside of the intervention sessions were not measured, as PA was just considered a secondary measure to control intensity during the ELFIT sessions. Thus, the effects of the intervention on participants' PA levels outside the school should be assessed in future studies. In addition, the sedentary control group did not experience the meaningful connection between words and gestures, unlike the LPA and MVPA groups. This makes it difficult to determine whether the observed benefits were due to physical activity itself or the interactive nature of the learning experience. Future studies should incorporate a non-active but gesture-based control group. This would help isolate the effects of movement intensity from the benefits of embodied learning. Future research should also be done to confirm the feasibility of implementing these interventions in large-scale studies, which should evaluate the long-term effects on physical and cognitive outcomes, identify barriers to delivery, and define the most effective intervention to maximize benefits.

5. Conclusions

Regardless of PA intensity, a school-based physically active learning intervention promoted the acquisition of foreign language vocabulary and induced improvements in overall cognitive performance (i.e., verbal memory, verbal comprehension) in preschool children. Interestingly, additional benefits were attained in the MVPA intervention group on several physical fitness indicators (i.e., muscle strength, speed-agility, cardiorespiratory fitness) and on the acquisition of foreign language vocabulary.

CRediT authorship contribution statement

Carlos Martin Martinez: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Augusto G. Zapico:** Conceptualization, Methodology, Writing – review & editing. **Pedro L. Valenzuela:** Conceptualization, Methodology, Formal analysis, Data curation, Writing – review & editing. **Asier Mañas:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision. **Oscar Martinez-de-Quel:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision.

Confirmation of ethical compliance

Ethical approval was obtained from the Research Ethics Committee at Universidad Complutense de Madrid (CE_20211118-16_SAL).

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Declaration of interest statement

None.

Appendix A. Supplementary data

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