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EFFECTIVENESS OF PHYSICAL-LITERACY-BASED ONLINE EDUCATION ON INDICES OF PHYSICAL ACTIVITY IN HIGH-SCHOOL ADOLESCENTS

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Abstract
Introduction. This study aimed to examine the effectiveness of a physical-literacy-based online education program on physical activity levels (PAL) and physical literacy (PL) components in high-school adolescents during the COVID-19 pandemic. ***Material and methods.*** A total of 544 Croatian adolescents (aged 14-18 years) participated in a 12-week intervention. Participants were randomly assigned to either an intervention group (n = 270) or a control group (n = 274). PAL was assessed using the Physical Activity Questionnaire for Adolescents (PAQ-A), while PL knowledge and perception were evaluated using the CAPL-2 Knowledge and Understanding (CAPL-2-KU) and PLAYself questionnaires. A total of 466 students completed both pre- and post-tests. Data were analyzed using two-way repeated measures ANOVA. ***Results.*** PAL decreased in both groups (PAQ-A: from 2.70 ± 0.70 to 2.52 ± 0.69; $p < 0.05$), with a smaller decline in the intervention group (–0.15) than in the control group (–0.21). CAPL-2-KU scores significantly increased in the intervention group (from 9.00 ± 2.04 to 9.73 ± 1.73; $p < 0.001$; $\eta^2 = 0.08$), indicating improved PL knowledge. Small but significant improvements were also observed in PLAYself total scores (from 68.46 ± 12.74 to 69.36 ± 11.93; $p = 0.001$; $\eta^2 = 0.02$). Gender analysis showed greater improvements among girls, particularly in CAPL-2-KU ($\eta^2 = 0.13$) and PLAYself total ($\eta^2 = 0.02$). ***Conclusions.*** The PL-based online education program effectively enhanced adolescents' PL knowledge and self-perception and mitigated the decline in PAL during a period of reduced school activity. Future interventions should integrate knowledge-based and experiential components to promote sustained engagement in physical activity.

Keywords: adolescent health, exercise, health education, physical education, lifestyle, distance learning

Introduction

Insufficient physical activity (PA) is recognized as a serious global public health problem of the 21st century [1]. The problem of insufficient PA, along with its consequences such as reduced physical fitness (PF), has been further exacerbated by the COVID-19 pandemic and social distancing measures. Numerous studies in the world and in Croatia show that the lack of PA is one of the main risk factors for chronic non-communicable diseases (NCD) and that it is the fourth leading cause of death, after hypertension, smoking, and diabetes [2]. Around a third of adults (31%) and as many as 81% of adolescents worldwide do not meet the World Health Organization (WHO) guidelines on recommended daily physical activity levels (PAL) [3]. However, in March 2020, the SARS-CoV-2 virus spread, and the COVID-19 pandemic was declared, which led to further decrease in PAL [4]. Indeed, the main way to control the pandemic was to introduce social distancing measures, which included the closure of schools, universities, cafes, restaurants, sports and recreational facilities, and other places for social gatherings [5].

Numerous studies have consistently reported a decrease in PAL worldwide due to social distancing measures during the pandemic around the globe in all populations [6, 7]. Numerous factors have been associated with the decline in PA during the pandemic, according to previous research. For example, substance abuse, urban living, and male gender have been identified as risk factors for the decline in PA in Croatian adolescents [8, 9, 10]. In addition, factors such as improved parental education, better parental support, higher levels of PA, and improved PL have been found to be able to halt the decline in PA levels during the COVID-19 pandemic [8, 11]. It has also been found that social distancing measures implemented during the COVID-19 pandemic significantly reduced PA, and adolescents have been identified as a particularly vulnerable group in this regard [11].

In 2015, the United Nations Educational, Scientific and Cultural Organization (UNESCO) highlighted PL as a key element for the development of quality education and sports programs and advised policymakers to pay more attention to this concept in order to encourage PA and improve health [12]. In a detailed analysis of this concept, Mandigo et al. state that PL is the foundation for the development of basic life skills in children, adolescents, and adults, enabling them to more easily face different life challenges [13]. PL can be defined as the ability to optimally use human potential, where an individual has the motivation, confidence, physical abilities, knowledge, and understanding to take responsibility for regular PA throughout life [14]. In addition, PL includes the fundamental behaviors, awareness, knowledge, and understanding associated with maintaining a healthy

and active life and making positive health decisions throughout life [15]. Accordingly, a physically literate individual is considered to have the motivation, confidence, knowledge, skills, and physical fitness to enjoy physical activity and to engage in behaviors that support optimal physical and mental health [16].

Some researchers believe that it is important to focus on acquiring knowledge about physical activities and fitness for the development of PL, including the transfer, ownership, and innovation of this knowledge [17]. Ennis emphasizes in his research that "knowledge is the core of physical literacy" [18], because it provides a basis for understanding what, how, and when to do, while Lundvall warns that without a focus on embodied knowledge, partly the ambition for PL is lost, which may result in adolescents not understanding the importance of lifelong learning through PA [19]. Researchers also believe that the education system overemphasizes the physical dimension; therefore, they suggest that more attention be paid to the knowledge and understanding of PL [20]. The application of knowledge is essential for problem-solving and the development of critical thinking. This approach can be particularly useful in urgent life circumstances such as the COVID-19 pandemic. Namely, the PL domain of knowledge and understanding can be adapted so that it does not require direct physical contact between "teachers" and "students," enabling systematic education on various aspects of PL, such as health segments, the importance of PL, specific knowledge about types of PA, exercises, and technical instructions, even when teachers and students are in a virtual environment, as was the case during the COVID-19 pandemic. Indeed, a recent Croatian study involved a 12-week PL-based education on adolescents and found out the improvement in physical fitness (i.e., cardiorespiratory fitness), which led to promising effects of PL on physical fitness and health [21]. However, it has not been investigated whether PL-based intervention could lead to changes in PAL among adolescents.

Although numerous studies have documented declines in adolescents' PA during the COVID-19 pandemic, most are observational and provide limited evidence on effective, modifiable interventions. Moreover, despite the growing recognition of PL as a key determinant of lifelong PA, experimental studies examining whether a physical-literacy-based online education program can mitigate declines in PA levels are scarce. Conceptually, the intervention was based on a causal pathway in which enhanced PL knowledge increases awareness and perceived competence, strengthens motivation and self-efficacy, and ultimately supports adaptive PA behavior under constrained environmental conditions. Therefore, this study aimed to examine the effectiveness of a 12-week physical-literacy-based online intervention on PA levels and PL components in high-school adolescents during the COVID-19 pandemic. It was hypothesized that the intervention would lead to significant improvements in PL knowledge and self-perception, and would attenuate the decline in PA levels compared with the control group.

Material and methods

Participants and Study Design

This study involved 544 Croatian adolescents (365 girls and 179 boys) aged 14 to 18 years at the beginning of the study, who were enrolled in the regular secondary education system of the Republic of Croatia. All students were in good health and did not have any injuries or illnesses during the study, which was proven by the ability to take part in the regular PE program. Health status was assessed prior to study inclusion through a combination of student self-report and parental/guardian consent forms, which included confirmation that the student had no medical conditions or injuries that would limit participation in regular physical education classes. In addition, physical education teachers confirmed students' eligibility based on their participation in standard school physical education without medical exemption. Students with acute injuries, chronic illnesses, or documented medical restrictions preventing participation in physical education were not included in the study. No participants were excluded during the intervention due to health-related reasons.

This study used a school-based convenience sampling approach. Secondary schools from different regions of Croatia were invited to participate through school administrations and physical education teachers. All students enrolled in selected classes were invited to participate in the study. Participation was voluntary, and no incentives were provided. Inclusion criteria were: (1) enrollment in regular secondary education, (2) age between 14 and 18 years at baseline, (3) attendance in regular physical education classes, and (4) provision of informed consent and assent. Exclusion criteria included medical conditions, injuries, or official medical exemptions that prevented participation in regular physical education classes, as well as incomplete baseline data.

As most participants were minors, written informed consent was obtained from parents or legal guardians prior to participation, which was administered during regular parental school meetings. Adolescents were additionally informed about the study aims, procedures, and voluntary nature of participation and provided their assent before data collection. Students were informed that they could withdraw from the study at any time without any consequences. A total of 544 adolescents were initially recruited. Of these, 466 participants completed both pre- and post-intervention assessments and were included in the final analysis. Attrition was primarily due to absence during post-testing (e.g., illness, quarantine, or other school-related absences) and incomplete follow-up data. No participants formally withdrew due to adverse effects or dissatisfaction with the intervention.

Students were randomly divided into two groups: intervention and control. There were 270 students in the intervention group and 274 students in the control group, and both groups were evenly divided by gender. Group allocation was performed at the class level to minimize contamination between students within the same school environment. Following baseline assessment, participating classes were randomly assigned to either the intervention or control condition using a simple random allocation procedure conducted by the research team. All students within a given class were assigned to the same study group. Teachers and students were informed of group allocation after baseline measurements were completed. Students from the intervention group, in addition to the regular physical education (PE) curriculum, participated in an educational intervention through a specially designed distance learning program once a week for twelve weeks. On the other hand, students from the control group followed only the regular PE curriculum, without any additional interventions. A total of 466 students completed the intervention and were tested at both initial and final testing points. The study received approval from the Ethical Board of the Faculty of Kinesiology at the University of Zagreb, Croatia (Ref. no. 25/2021, approval date: 16 July 2021) and it was undertaken in compliance with the Helsinki Declaration. The study design and timeline is detailed in Figure 1.

The data collection and measurement procedures were identical in all schools. Before the start of the research, students

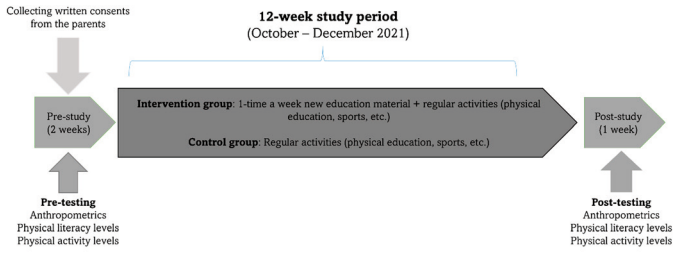

Fig. 1. The Structural Model of the Hypotheses Tests

were informed in detail about the purpose, content, and method of conducting the research. They were also explained that participation was completely voluntary and anonymous and that they could withdraw at any time. The research was conducted in sports halls, and students completed the questionnaires during PE classes via a link they received on their mobile devices or by scanning a QR code independently. The average time required to complete the questionnaire was ten minutes. The students completed the questionnaires at a sufficient distance from others to maintain privacy and respond independently. If they had any questions or concerns, they could contact the PE teacher or the research leader, who were present during the data collection. Measurements were also conducted during PE classes in sports halls, where there was enough space to maintain the privacy of the respondents when performing tests that required privacy. Post-intervention measurements were conducted immediately following the winter school holiday period. This timing was chosen due to uncertainty related to potential COVID-19-related school closures and the need to complete follow-up assessments while in-person data collection was still feasible. Both intervention and control groups were assessed during the same period, thereby controlling for seasonal and holiday-related influences at the group level. Although no seasonal adjustment was applied in the statistical analyses, the potential influence of the winter holiday period on physical activity levels is acknowledged in the interpretation of the results.

Intervention Program

The intervention was implemented from October to December 2021, and included specific, short-term educational programs aimed at improving knowledge and understanding of PL among adolescents. For this purpose, various educational video materials were developed that included information on the health benefits of PA, the importance of proper nutrition, and ways to increase PA in confined spaces and with limited resources, reflecting circumstances similar to the situation caused by COVID-19. Over the course of 12 weeks, video materials were distributed to students via selected platforms (the social network Yammer and Microsoft Teams). Engagement with the intervention materials was supported through controlled distribution via the closed Microsoft Teams /Yammer platform, which was accessible only to students assigned to the intervention group. Access to the educational videos required individual login credentials provided through the official school system. Teachers regularly reminded students to access and review the weekly materials during the intervention period. Although individual viewing analytics (e.g., detailed view counts or viewing duration) were not systematically extracted for research purposes, access to the materials was restricted to registered participants within the designated Teams /Yammer group, ensuring controlled exposure to the intervention content. No formal minimum viewing threshold was imposed, as the intervention was designed as an educational support component rather than a graded curricular requirement. In the initial weeks of the intervention, the emphasis was on cardiovascular endurance. Namely, after an introductory video that covered the basic concept of PL, three videos followed in the first three weeks that dealt with the topic of cardiovascular endurance. In the first video, students were introduced to the concept of cardiovascular endurance, in the second they were presented with its basic parameters, and in the third the same information was repeated, but in a different way, with additional explanations, synonyms for this concept and advice on how to improve cardiovascular endurance and its health benefits. They were also presented with specific "recipes" for improving this ability. The next three videos dealt with the concept and definition of muscular strength, while two videos dealt with flexibility, and two videos were dedicated to proper nutrition. In the last week of the intervention, students were given a final video that covered all previously covered topics and further explained the concept of PL. The educational video materials used in the intervention are described in detail elsewhere and are published in open access [21].

Variables and Measurements

The following variables were analyzed in this study: PA, morphological anthropometric variables, PF, and the domain of knowledge and understanding of PL. The PAQ-A questionnaire [22] was used to indirectly assess PAL. The PAQ-A is a self-administered tool that measures PA in the past seven days, with the aim of measuring the activity levels of adolescents aged 14 to 18 years. The reliability and validity of this questionnaire were confirmed in studies conducted on adolescents from Croatia and Bosnia and Herzegovina [23, 24]. The questionnaire consists of nine items. The first item assesses PA in leisure time (e.g. cycling, walking, running, dancing, football); the second relates to activity during PE classes; the third assesses activity during lunch break; the fourth relates to PA immediately after school; the fifth to activity in the evening; the sixth to activity during the weekend; the seventh assesses general activity during leisure time; the eighth measures the frequency of PA during the week; while the ninth item identifies respondents who are ill, injured, or have any other reason for reduced PA, and is not included in the final score. Items 1 to 8 are rated on a scale of 1 to 5, with 1 indicating low or no activity and 5 indicating a high level of activity. The final PAQ-A score is calculated as the arithmetic mean of the scores of all items [25]. Students answered the questionnaire using an electronic version that has been recently developed and described in detail in other works [8, 10].

Morphological anthropometric variables included body height, sitting body height, body mass and body mass index. Body height was measured with an altimeter while the students were standing barefoot on a flat and firm surface, in an upright position with their gaze directed straight ahead. The result was read on a scale with an accuracy of 0.1 centimeter. Sitting body height was also measured with an altimeter while the students were sitting upright on a chair, with their head in the Frankfurt horizontal position. The distance from the surface to the crown of the head was measured, and the result was read with an accuracy of 0.1 centimeter. For body mass measurement, the students stood barefoot, in an upright position on a digital diagnostic scale (Omron BF 511), wearing a sports shirt and shorts. The result was read in kilograms with an accuracy of 0.1 kilogram. Body mass index was calculated according to the formula: body mass index = body mass (kg) / body height (m)^2 (26). PF was measured with the standing long jump, sit and reach test, beep test, and maximum number of trunk lifts in 60 seconds.

These tests are regularly used in the Croatian school system, and their reliability was confirmed by previous research [27, 28].

The Croatian version of the CAPL-2-Knowledge and Understanding questionnaire [29] was used to assess the knowledge and understanding domain of PL. Two experienced researchers translated the original questionnaire into Croatian, after which a third researcher back-translated it into English. The final version was reviewed by a native English speaker. The Croatian version of the questionnaire was harmonized and corrected, especially in cases where the terms were unclear to the two researchers. Self-perceived physical literacy was assessed using the PLAYself questionnaire, a component of the Physical Literacy Assessment for Youth (PLAY) tools developed to evaluate individuals' perception of their own physical literacy. Unlike performance-based measures, PLAYself captures the affective and cognitive dimensions of physical literacy by assessing perceived competence, confidence, and engagement in physical activity contexts. The instrument consists of multiple subdomains that reflect key dimensions of physical literacy: (1) environmental engagement (confidence and comfort participating in diverse physical environments), (2) self-description (self-perceived physical competence and confidence), (3) literacy (understanding of physical activity concepts and terminology), (4) numeracy (ability to interpret basic activity-related quantitative information), and (5) overall physical literacy perception. Items are rated on a Likert-type scale, and subscale scores are calculated by summing or averaging the corresponding items, with higher scores indicating higher perceived physical literacy. PLAYself scores were analyzed both at the subdomain level and as a total score to capture global changes in self-perceived physical literacy following the intervention. The reliability and validity of the Croatian version of the CAPL-2 and PLAYself questionnaire were confirmed in a previous study [30].

Statistical Analysis

The normality of the data distribution for all examined fitness and anthropometric variables was assessed using the Kolmogorov-Smirnov test. Additionally, Levene's test was employed to evaluate the homogeneity of variance across the variables. As all variables satisfied the assumption of normality, descriptive statistics were reported in terms of means and standard deviations. To analyze the effects of the intervention, a two-way repeated measures analysis of variance (ANOVA) was conducted. The primary factors in the ANOVA model included "Time" (comparing pre- and post-intervention measurements) and "Group" (Intervention vs. Control), with the interaction term "Time × Group" included to assess differential effects of the intervention over time. To determine the effect size (ES) of the observed differences, partial eta squared (μ^2) was computed and interpreted according to established thresholds according to Cohen's conventional guidelines for ANOVA designs: small effect (ES > 0.02), medium effect (ES > 0.13), and large effect (ES > 0.26). These cut-offs were adopted to facilitate interpretation of practical significance and comparability with prior physical activity and physical literacy intervention studies. All statistical analyses were performed using Statistica 13.5 (TIBCO Software Inc., Palo Alto, CA, USA), with a significance threshold set at $p < 0.05$.

Results

Descriptive statistics of the pre- and post-testing for the total sample (i.e., without division by gender) and the significance of the t-test differences between pre- and post-testing are presented in table 1. Overall, physical activity levels decreased in both groups, although the decline was less pronounced in the intervention group. In contrast, physical literacy knowledge and understanding (CAPL-2-KU) increased significantly following the intervention, with greater improvements observed in the intervention group than in the control group. Small but statistically significant improvements in self-perceived physical literacy were also observed in the intervention group, particularly for the PLAYself self-description subdomain and total score.

Table 2 presents the results of the two-way repeated measures analysis of variance (ANOVA) for the total sample, with partial eta squared (μ^2) values indicating the magnitude of the effect size. A significant time effect was found for PAQ-A (small ES), CAPL-2-KU (small ES), and PLAYself total (small ES), suggesting that changes over time were present but not substantial. A significant group effect was observed for CAPL-2-KU (small ES), indicating that differences between groups had a small effect. Additionally, significant group × time interactions were found for PLAYself total (small ES) and PLAYself 2 (small ES), indicating that the intervention had a small effect on these variables, with differences in responses between the groups.

Table 1. Descriptive statistics for pre- and post-testing for the total sample with data given as means and standard deviations, and univariate differences between pre- and post-testing results.

	Total sample (n = 466)		Control group (n = 212)		Intervention group (n = 254)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
PAQ-A	2.70 ± 0.70	2.52 ± 0.69	2.66 ± 0.69	2.45 ± 0.70	2.73 ± 0.71	2.58 ± 0.68
CAPL-2-KU	8.63 ± 2.13	9.32 ± 1.93	8.18 ± 2.15	8.8 ± 2.04	9.00 ± 2.04	9.73 ± 1.73
PLAYself total	68.46 ± 12.74	69.36 ± 11.93	67.34 ± 12.54	69.48 ± 11.86	69.36 ± 12.85	69.25 ± 12.01
PLAYself 1	50.66 ± 16.65	52.02 ± 16.58	49.46 ± 15.39	51.82 ± 16.00	51.64 ± 17.57	52.19 ± 17.06
PLAYself 2	70.96 ± 17.04	71.89 ± 15.77	69.38 ± 16.55	71.54 ± 15.57	72.23 ± 17.35	72.17 ± 15.95
PLAYself 3	79.99 ± 19.33	79.78 ± 18.31	79.73 ± 19.84	80.87 ± 17.79	80.20 ± 18.94	78.90 ± 18.70
PLAYself 4	63.68 ± 23.68	64.57 ± 23.24	63.25 ± 24.16	65.89 ± 23.32	64.03 ± 23.33	63.51 ± 23.17
PLAYself 5	86.66 ± 17.39	87.63 ± 17.01	85.32 ± 18.45	87.66 ± 17.68	87.74 ± 16.45	87.61 ± 16.48

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Descriptive statistics for boys are presented in table 3. Physical activity levels decreased from pre- to post-testing in both groups, with a slightly greater decline observed in the control group, suggesting a modest protective effect of the intervention. In contrast, PL knowledge and understanding improved notably in the intervention group, while only minimal changes were observed in the control group. Self-perceived PL remained largely stable, with small positive changes in the intervention group, particularly in the PLAYself self-description and environmental subdomains.

Table 4 presents the ANOVA results for boys, analyzing main effects of group and time, as well as their interaction. Significant group effects were found for CAPL-2-KU (small ES) and PAQ-A (small ES), indicating small differences between the intervention and control groups. A significant time effect was observed for PAQ-A (small ES), CAPL-2-KU (small ES), and PLAYself 2 (small ES), suggesting that these measures improved over time but with a small effect size. Furthermore, significant group × time interactions were detected for PLAYself total (small ES), PLAYself 1 (small ES), and PLAYself 2 (small ES), demonstrating that the intervention produced small but meaningful differences in how these measures changed over time between groups.

Descriptive statistics for girls are presented in table 5. Physical activity levels decreased in both groups from pre- to post-testing, although the decline was smaller in the intervention group. The largest improvements were observed in PL knowledge and understanding, with a substantial increase in CAPL-2-KU scores in the intervention group and only minor changes in the control group. Small but positive improvements in self-perceived PL were also evident in the intervention group, particularly in the PLAYself total score and self-description-related subdomains.

Table 6 presents the ANOVA results for girls, analyzing the main effects and interactions. A significant time effect was found for PAQ-A (small ES) and CAPL-2-KU (moderate ES), indicating that these measures improved over time, with CAPL-2-KU demonstrating a moderate effect. A significant group effect was observed for CAPL-2-KU (small ES), suggesting small differences between the intervention and control groups. Additionally, a significant group × time interaction was found for PLAYself total (small ES), indicating that the intervention had a small impact on how self-perception changed over time in girls.

Table 2. Results of the two-way repeated measures analysis for total sample (μ2 – partial eta squared values – effect size).

	Main effects						Interaction		
	Group			Time			(Group × Time)		
	F test	p	μ2	F test	p	μ2	F test	p	μ2
PAQ-A	2.88	0.09	0.01	41.01	0.001	0.08	1.17	0.28	0.001
CAPL-2-KU	34.22	0.00	0.07	42.76	0.001	0.08	0.23	0.63	0.001
PLAYself total	0.68	0.41	0.001	9.29	0.001	0.02	11.30	0.00	0.02
PLAYself 1	0.80	0.37	0.001	7.24	0.01	0.01	2.80	0.09	0.01
PLAYself 2	1.44	0.23	0.001	7.10	0.01	0.01	7.90	0.01	0.02
PLAYself 3	0.25	0.62	0.001	0.01	0.93	0.001	2.09	0.15	0.001
PLAYself 4	0.17	0.68	0.001	1.19	0.28	0.001	2.61	0.11	0.01
PLAYself 5	0.73	0.39	0.001	2.08	0.15	0.001	2.59	0.11	0.01

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Table 3. Descriptive statistics for pre- and post-testing for boys with data given as means ± standard deviations, and univariate differences between pre- and post-testing results.

	Total sample (n = 148)		Control group (n = 62)		Intervention group (n = 86)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
PAQ-A	2.93 ± 0.76	2.74 ± 0.75	2.83 ± 0.77	2.56 ± 0.81	3.01 ± 0.74	2.88 ± 0.68
CAPL-2-KU	8.68 ± 2.11	9.16 ± 2.36	8.4 ± 1.8	8.55 ± 2.34	8.88 ± 2.3	9.6 ± 2.28
PLAYself total	69.58 ± 13	70.24 ± 11.5	67.94 ± 13.5	70.51 ± 11.73	70.75 ± 12.58	70.05 ± 11.39
PLAYself 1	52.36 ± 17.72	51.97 ± 16.73	49.46 ± 17.85	51.61 ± 15.94	54.46 ± 17.43	52.23 ± 17.36
PLAYself 2	74.8 ± 16.81	75.92 ± 15.07	71.38 ± 17.46	74.87 ± 16.2	77.26 ± 15.97	76.68 ± 14.24
PLAYself 3	73.92 ± 20.74	74.29 ± 20.63	75.68 ± 20.58	77.53 ± 17.45	72.67 ± 20.89	72 ± 22.44
PLAYself 4	62.57 ± 24.6	63.62 ± 24.19	65.27 ± 25.6	66.73 ± 24.21	60.65 ± 23.83	61.41 ± 24.07
PLAYself 5	85.41 ± 18.08	85.93 ± 18.43	85.32 ± 20.02	19.62 ± 2.51	85.48 ± 16.69	17.66 ± 1.9

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Table 4. Results of the two-way repeated measures analysis for boys (μ2 – partial eta squared values – effect size).

	Main effects						Interaction		
	Group			Time			(Group × Time)		
	F test	p	μ2	F test	p	μ2	F test	p	μ2
PAQ-A	4.82	0.03	0.03	10.64	0.001	0.07	1.11	0.29	0.01
CAPL-2-KU	6.86	0.01	0.04	3.80	0.05	0.03	1.68	0.20	0.01
PLAYself total	0.37	0.55	0.001	1.99	0.16	0.01	6.09	0.01	0.04
PLAYself 1	1.07	0.30	0.01	0.001	0.97	0.001	5.56	0.02	0.04
PLAYself 2	2.32	0.13	0.02	3.44	0.07	0.02	6.75	0.01	0.04
PLAYself 3	1.98	0.16	0.01	0.13	0.72	0.001	0.58	0.45	0.001
PLAYself 4	1.87	0.17	0.01	0.36	0.55	0.001	0.03	0.85	0.001
PLAYself 5	0.001	0.99	0.001	0.13	0.72	0.001	0.01	0.91	0.001

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Table 5. Descriptive statistics for pre- and post-testing for girls with data given as means ± standard deviations, and univariate differences between pre- and post-testing results.

	Total sample (n = 332)		Control group (n = 153)		Intervention group (n = 179)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
PAQ-A	2.60 ± 0.66	2.43 ± 0.64	2.60 ± 0.64	2.40 ± 0.64	2.61 ± 0.67	2.45 ± 0.64
CAPL-2-KU	8.61 ± 2.14	9.39 ± 1.70	8.08 ± 2.28	8.91 ± 1.91	9.06 ± 1.91	9.79 ± 1.38
PLAYself total	67.95 ± 12.61	68.96 ± 12.12	67.10 ± 12.17	69.07 ± 11.93	68.68 ± 12.96	68.87 ± 12.30
PLAYself 1	49.90 ± 16.12	52.05 ± 16.54	49.90 ± 16.12	51.91 ± 16.07	50.28 ± 17.52	52.16 ± 16.96
PLAYself 2	69.24 ± 16.88	70.09 ± 15.77	68.58 ± 16.15	70.19 ± 15.16	69.82 ± 17.51	70.01 ± 16.31
PLAYself 3	82.67 ± 18.06	82.21 ± 16.64	81.34 ± 19.38	82.2 ± 17.81	83.81 ± 16.83	82.22 ± 15.63
PLAYself 4	64.17 ± 23.28	65.00 ± 22.84	62.44 ± 23.59	65.55 ± 23.03	65.65 ± 22.98	64.52 ± 22.72
PLAYself 5	87.22 ± 17.08	88.39 ± 16.31	85.32 ± 17.85	88.31 ± 16.87	88.83 ± 16.27	88.46 ± 15.87

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Table 6. Results of the two-way repeated measures analysis for girls (μ2 – partial eta squared values – effect size).

	Main effects						Interaction		
	Group			Time			(Group × Time)		
	F test	p	μ2	F test	p	μ2	F test	p	μ2
PAQ-A	0.20	0.65	0.001	31.36	0.001	0.09	0.29	0.59	0.001
CAPL-2-KU	28.71	0.001	0.08	47.61	0.001	0.13	0.17	0.68	0.001
PLAYself total	0.28	0.60	0.001	7.85	0.01	0.02	5.42	0.02	0.02
PLAYself 1	0.10	0.75	0.001	10.79	0.001	0.03	0.18	0.67	0.001
PLAYself 2	0.09	0.76	0.001	4.04	0.05	0.01	2.49	0.12	0.01
PLAYself 3	0.57	0.45	0.001	0.14	0.71	0.001	1.58	0.21	0.001
PLAYself 4	0.23	0.63	0.001	0.74	0.39	0.001	3.41	0.07	0.01
PLAYself 5	1.28	0.26	0.001	2.21	0.14	0.01	3.64	0.06	0.01

PAQ-A – physical activity level measured using the physical activity questionnaire for adolescents; CAPL-2-KU – Canadian Assessment of Physical Literacy Knowledge and Understanding domain; PLAYself 1 – environment subdomain of the PLAYself questionnaire; PLAYself 2 – self-description subdomain of the PLAYself questionnaire; PLAYself 3 – literacy subdomain of the PLAYself questionnaire; PLAYself 4 – numeracy subdomain of the PLAYself questionnaire; PLAYself 5 – physical literacy subdomain of the PLAYself questionnaire; PLAYself – total score for the PLAYself questionnaire.

Discussion

This study examined the effectiveness of a PL-based online education program in influencing PAL and PL knowledge and perception among high school adolescents. The findings indicate that while overall PAL declined across both the intervention and control groups, the intervention helped mitigate this reduction, particularly among girls. The most notable impact of the program was observed in PL knowledge and understanding, where participants in the intervention group demonstrated a significant improvement compared to those in the control group, with females exhibiting greater improvement. Additionally, self-perception of PL showed small yet meaningful positive changes, suggesting that the program contributed to greater confidence and awareness regarding PA.

Effects of physical literacy intervention on physical activity levels

A negative change in the results was observed for the PAQ-A variable, i.e., the students' PAL decreased overall from the initial to the final measurement. The main reason for such changes should be sought in the timing of the initial and final measurements. Specifically, the final measurement was conducted immediately after the winter school holidays, which lasted three weeks. During the holidays and winter months, students are less physically active and likely spend more time engaged in sedentary screen-based activities, such as playing video or computer games as well as communicating with their peers in the virtual world via their mobile devices, or simply following events on social networks. In turn, during the school year, their school and other obligations (sports, recreation) still require a more dynamic organization of their free time [31, 32]. Therefore, it is quite logical that during the final measurement, students estimated that they were less active during the winter holidays than at the beginning of the school year in the fall, when the initial measurement was conducted during regular PE classes. It should be emphasized here that the research was conducted during the COVID-19 pandemic. This was an unusual situation in which classes were interrupted several times during the year. Given that the main author of this paper is a PE teacher, she was informed that there was a possibility of classes being interrupted again. Although the optimal timing of the final measurement was initially considered, due to the risk of another lockdown and a transition to distance learning, it was ultimately conducted immediately after students returned from the winter holidays. This proved to be the best solution because it was exactly ten days after the students returned to school after the holidays that the transition to distance learning took place again.

The intervention group's PAL might have increased over the course of the program, but the final measurement might not have adequately reflected this effect. The fact that the post-testing was done directly after the school break, when students often participate in fewer organized PA and report lower PAL, could be one explanation for this. Even if students' PL and motivation for an active lifestyle had grown, they might have felt less active in the absence of structured PE classes, access to sports facilities, and regular school schedules. Thus, potential gains in PAL that might have taken place throughout the intervention period may have been obscured by this seasonal volatility. However, it has to be mentioned that the intervention group only slightly decreased PAL, which means that the intervention might have helped mitigate this reduction. Thus, even if it was not fully displayed, the students in the intervention group may have had increased knowledge and consciousness of the importance of regular PA, which helped them to reduce their PAL less than the control group students. Moreover, even though the reduction in PAL was present in both boys and girls, the reduction was greater in boys. This may mean that the intervention had a protective effect on PAL in girls, although it did not completely prevent a decline in PAL. Also, a greater decrease in PAL in boys can be explained by the fact that boys are usually more active because they participate more often in organized physical activities compared to girls, who are more inclined to informal forms of activities such as dancing, yoga, walking, etc. [33]. Thus, since during the holidays sports clubs also reduce or fully pause their activities, that could be the reason why boys decreased their PAL more than girls.

Effects of physical literacy intervention on physical literacy levels

The findings of this study suggest that while the intervention did not lead to a dramatic increase in PAL, it contributed positively to knowledge acquisition and self-perceived competence in PL. Firstly, the most significant improvement was observed in the Canadian Assessment of Physical Literacy Knowledge and Understanding (CAPL-2-KU) scores, which showed a significant increase in the intervention group. This suggests that online educational intervention was effective in improving students' theoretical understanding of PL. Previous research has highlighted the importance of PA knowledge and understanding, as they enable individuals to make informed decisions regarding their engagement in PA [19, 20]. The intervention, which included educational videos covering topics such as the health benefits of PA, balanced nutrition, and different forms of exercise, likely played a key role in driving this improvement. By presenting practical examples instead of abstract concepts, the intervention made PL more understandable and relevant to everyday life. This form of learning supports the idea that adolescents benefit when PE includes both movement and clear information about why and how regular activity matters.

Secondly, the results for female participants show a more pronounced effect of the intervention on PL measures. This finding supports previous research indicating that girls are more responsive to educational interventions that emphasize knowledge and understanding of PL concepts and health awareness [17], which may contribute to long-term engagement in physical activity. The intervention likely provided a structured and supportive environment for girls to develop a greater understanding of PL, which is often overlooked in traditional PE settings. The online format may have given them a sense of comfort and control that traditional classes sometimes lack. It also provided a setting where understanding and self-confidence could develop alongside physical skills. This combination appears to help girls build a stronger sense of ownership over their health and activity habits. Future work should continue to combine factual learning with experience-based approaches so that both knowledge and behavior are strengthened in a balanced way.

Limitations and Strengths

Several limitations of this study should be acknowledged. First, the school-based sampling approach limits the generalizability of the findings beyond Croatian high-school adolescents. Second, PA levels were assessed using a self-reported questionnaire, which may be subject to recall bias and social desirability effects. Third, post-intervention measurements were conducted immediately after the winter holiday period, which may have influenced reported PA levels due to seasonal and holiday-re-

lated reductions in activity. However, both intervention and control groups were assessed during the same period, partially controlling for this effect. Finally, although the intervention improved PL knowledge and self-perception, its online and knowledge-focused nature may have limited its capacity to produce larger changes in PA behavior. Future studies should combine educational components with structured, experiential activity-based interventions and include longer follow-up periods to assess sustained behavioral effects.

Despite these limitations, the study also has several notable strengths. The large sample size and inclusion of both male and female adolescents enhance the robustness of the findings. The controlled school-based design, with comparable intervention and control groups assessed at identical time points, strengthens internal validity. In addition, the study addresses an important and timely research gap by evaluating a physical-literacy-based online intervention implemented under real-world pandemic conditions, providing practical insights for educational and public health strategies during periods of restricted physical activity. The focus on multiple dimensions of physical literacy further supports a comprehensive understanding of the intervention's effects.

Conclusion

This study highlights the positive influence of an online PL-based educational program on students' PL knowledge and self-perception, with notable differences in impact between genders. While overall PAL declined across the sample due to specific terms (i.e., COVID-19 pandemic), the intervention helped reduce this decline, particularly among female participants. To enhance the effectiveness of future interventions, strategies such as virtual engagement initiatives and structured at-home activity programs should be explored to sustain PAL during school breaks. Additionally, adapting interventions to align with gender-specific preferences may further optimize their impact. By improving knowledge, motivation, and self-confidence, PL interventions have the potential to support adolescents in maintaining long-term participation in PA. Future studies should investigate the integration of both knowledge-based and skill-based approaches to maximize the effectiveness of PL education across diverse populations.

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