Effect of Dance-Based Exergaming on Mental Rotation, General Motor Coordination, and Math Achievement in Adolescent Students: Pilot Interventional Study

Patrick Fargier, Valérian Cece, Vanessa Lentillon-Kaestner, Cédric Roure

Submitted to: JMIR Serious Games
on: August 20, 2025

Table of Contents

Effect of Dance-Based Exergaming on Mental Rotation, General Motor Coordination, and Math Achievement in Adolescent Students: Pilot Interventional Study

Patrick Fargier[1] PhD, Prof Dr; Valérian Cece[2] PhD; Vanessa Lentillon-Kaestner[2*] PhD, Prof Dr; Cédric Roure[2*] PhD, Prof Dr

[1] University of Teacher Education, State of Vaud (HEP VD), Inter?University Laboratory on Human Movement Biology (LIBM), University of Lyon, University Claude Bernard Lyon 1, France Lausanne CH
[2] University of Teacher Education, State of Vaud (HEP VD) Lausanne CH
[*]these authors contributed equally

Corresponding Author:
Patrick Fargier PhD, Prof Dr

University of Teacher Education, State of Vaud (HEP VD), Inter?University Laboratory on Human Movement Biology (LIBM), University of Lyon, University Claude Bernard Lyon 1, France
Avenue de cour 33
Lausanne
CH

Abstract

Background: Exergaming can promote adolescent health by encouraging the repetition of game-related tasks, thereby potentially contributing to academic success by developing motor and cognitive skills. Studies highlighted the influence of practicing exergames on motor skills learning, but without clarifying the influence of this practice on general motor coordination. Other studies have suggested that exergames may influence math success, particularly in the case of a non-mathematical, dance-based exergame. According to the literature, this might be linked to mental rotation or general motor coordination training. However, the influence, in the same subjects, of a given exergaming sequence on these abilities and on math achievement remained to be studied.

Objective: This pilot interventional study aimed to determine whether non-mathematical dance-based exergaming may improve mental rotation, general motor coordination, and math achievement in adolescent students.

Methods: An experimental group (EG) with 15 girls and 15 boys (mean 14.0, SD 0.7 years) and a control group (CG) with 14 boys and 12 girls (mean 14.2, SD 0.9 years) participated in the study. EG was involved in dance-based exergaming (DEx) with different types of locomotion and interlimb coordination, and CG, in exergaming based on precision ball-throwing (TEx), requiring catching and throwing a ball. Only DEx involved mental rotation, and neither DEx nor TEx involved mathematical content. DEx and TEx were sequences of 5 weekly 45-minute sessions, implemented using the Lü platform. A pretest-posttest design allowed to compare DEx and TEx influence on (1) a mental rotation test, (2) locomotion and sprint tests, and (3) quantity comparison tests and simple and complex addition and multiplication tests. Each session led to non-instrumented observation, and sessions 3 and 5, to instrumented tracking of physical activity and situational interest.

Results: Monitoring of the sequences showed only a significant between-group difference in terms of triggered situational interest in session 5 (MANOVA results with $F_{1,54}=9.15$, $P=.004$, $?p^2=.14$). The variable was added as a covariate in the ANCOVAs with GLM approach performed further. ANCOVA results showed an advantage for EG over CG in terms of mental rotation ($F_{1,52}=6.17$, $P=.016$, $?p^2=.11$), number of correct simple additions ($F_{1,52}=8.26$, $P=.006$, $?p^2=.14$), and error rate in complex addition ($F_{1,52}=8.40$, $P=.005$, $?p^2=.14$). No other significant results were found; locomotor performance improved in EG (by 3%) and CG (by 5%) from pretest to posttest.

Conclusions: DEx improved mental rotation efficiency and only calculations involving mental rotation, according to the literature. Further research is needed to clarify whether such improvement in calculation is linked to mental rotation training itself and whether training general motor coordination might influence this improvement.

(JMIR Preprints 20/08/2025:82610)
DOI: https://doi.org/10.2196/preprints.82610

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http
No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <a href="https:/

Original Manuscript

Original Paper

Effect of Dance-Based Exergaming on Mental Rotation, General Motor Coordination, and Math Achievement in Adolescent Students: Pilot Interventional Study

[1,2]Patrick Fargier, [1]Valérian Cece, [1]Vanessa Lentillon-Kaestner, [1]Cédric Roure

[1]University of Teacher Education (HEP VD), Lausanne, State of Vaud, Switzerland.
[2]Inter-University Laboratory on Human Movement Biology (LIBM), University of Lyon, University Claude Bernard Lyon 1, Villeurbanne, France.

Corresponding author: Patrick Fargier, +33(0)618271153, patrick.fargier@hepl.ch

Keywords: Dance-based exergaming, Mental rotation, General motor coordination, Math achievement

Abstract

Background: Exergaming can promote adolescent health by encouraging the repetition of game-related tasks, thereby potentially contributing to academic success by developing motor and cognitive skills. Studies highlighted the influence of practicing exergames on motor skills learning, but without clarifying the influence of this practice on general motor coordination. Other studies have suggested that exergames may influence math success, particularly in the case of a non-mathematical, dance-based exergame. According to the literature, this might be linked to mental rotation or general motor coordination training. However, the influence, in the same subjects, of a given exergaming sequence on these abilities and on math achievement remained to be studied.

Objective: This pilot interventional study aimed to determine whether non-mathematical dance-based exergaming may improve mental rotation, general motor coordination, and math achievement in adolescent students.

Methods: An experimental group (EG) with 15 girls and 15 boys (mean 14.0, SD 0.7 years) and a control group (CG) with 14 boys and 12 girls (mean 14.2, SD 0.9 years) participated in the study. EG was involved in dance-based exergaming (DEx) with different types of locomotion and interlimb coordination, and CG, in exergaming based on precision ball-throwing (TEx), requiring catching and throwing a ball. Only DEx involved mental rotation, and neither DEx nor TEx involved mathematical content. DEx and TEx were sequences of 5 weekly 45-minute sessions, implemented using the Lü platform. A pretest-posttest design allowed to compare DEx and TEx influence on (1) a mental rotation test, (2) locomotion and sprint tests, and (3) quantity comparison tests and simple and complex addition and multiplication tests. Each session led to non-instrumented observation and sessions 3 and 5, to instrumented tracking of physical activity and situational interest.

Results: Monitoring of the sequences showed only a significant between-group difference in terms of triggered situational interest in session 5 (MANOVA results with F1,54=9.15, P=.004, η_p^2=.14). The variable was added as a covariate in the ANCOVAs with GLM approach performed further. ANCOVA results showed an advantage for EG over CG in terms of mental rotation (F1,52=6.17, P=.016, η_p^2=.11), number of correct simple additions (F1,52=8.26, P=.006, η_p^2=.14), and error rate in complex addition (F1,52=8.40, P=.005, η_p^2=.14). No other significant results were found; locomotor performance improved in EG (by 3%) and CG (by 5%) from pretest to posttest.

Conclusions: DEx improved mental rotation efficiency and only calculations involving mental rotation according to the literature. Further research is needed to clarify whether such improvement in calculation is linked to mental rotation training itself and whether training general motor coordination might influence this improvement.

Effect of Dance-Based Exergaming on Mental Rotation, General Motor Coordination, and Math Achievement in Adolescent Students: Pilot Interventional Study

Introduction

Background

The digital revolution belongs to a new techno-economic paradigm that has led to the development of a gaming sector with a commercial and entertainment aim [1]. Since the 1970s, this has led to the creation of different genres of video games played using an audiovisual device to interact with a virtual environment under defined rules, conditions, and complexity levels [2]. Such games became part of popular culture and researchers gradually saw them as potentially useful for academic learning [3]. Studies reported positive effects of practicing entertainment video games on cognitive functions and abilities that promote school achievement [4,5]. The literature also emphasized that video games embedding a pedagogical aim, thus considered serious games, proved useful for sustaining learning activity over time and promoting learning success [6]. Moreover, manufacturers have developed *active* video games, also known as exergames, for entertainment and educational purposes. Although sharing characteristics with conventional video games, exergames require locomotion and movements of bodily segments not limited to the use of keyboards, joysticks, or other portable controllers [7]. These video games are thus likely to encourage physical activity, and as a result, to have a significant influence on health but also school achievement [8].

From the outset, authors have argued that exergames may influence health by favoring physical training and a positive attitude towards physical activity [9]. Consistently, studies showed that exergaming generally elicits, at least in the short term, positive emotions [10-12] and well-being [13,14] in children and adolescents. Other studies showed that the eventual decline over time in the appeal of a given exergame [15] can be avoided by specific practice modalities [10]. Furthermore, the literature reported that such influence on interest may favor energy expenditure [16]. Accordingly, studies found that exergaming may reduce perceived exertion [17], promote intense efforts [18], and have a positive impact on physical fitness [19,20]. On the other hand, the attractiveness of practicing an exergame might favor the repetition of the tasks to be performed when exergaming, thus learning these tasks, as authors have long considered repetition to be a key element of learning [21,22].

Most studies examined such possible influence of exergaming on motor learning outside the school context, and especially fundamental motor skills learning. These encompass “balance/stability skills” (e.g., one-foot balance), “object control skills” (e.g., throwing), and “locomotor skills” (e.g., jumping), rooted in physical fitness (e.g., coordination) and form a basis for learning and performing different types of physical activity [23-25]. Mastery of these motor skills is thus likely to encourage long-term commitment to physical activity, with all its attendant health benefits (e.g., [26,27]). Interestingly, reviews and meta-analyses highlighted that exergaming may develop balance and postural stability [23,28]. A meta-analysis also found a positive influence of exergames involving actions such as catching, or kicking, on performance in a test assessing object control skills [25]. On the other hand, although a few experimental results suggested the possible influence of exergaming on locomotor skills in children and adolescents [29,30], reviews and meta-analyses found that such findings require confirmation (e.g., [23]). Especially, whether exergaming might develop general motor coordination (i.e., the ability to coordinate several limbs and the whole body [31] as a basis for locomotor skills [23]) remains, to our knowledge, to be clarified.

Furthermore, the influence of exergaming on school achievement has been little studied to date, although studies emphasized that active learning, which links movement and learning, may be a promising way to reduce sedentary behavior while improving academic performance [32,33]. Two recent studies reported a positive influence of practicing exergames with math content on motivation and learning in the areas involved by the exergames, which is in line with the literature on serious games [6]. One of these studies found a positive influence on motivation in math, but not on math achievement, and on physical literacy level [34]. The other study found that exergaming, based on ball throws to hit points after identifying them in a Cartesian coordinate system, increased the performance of a paper-and-pencil task of identifying points in such a coordinate system, as well as the accuracy of ball throws at a target [35]. A 2013 study also reported the influence of practicing a non-mathematical exergame, based on aerobic dance, not only on children's performance in a 1-mile run, but also on math scores on the Utah Criterion-Referenced Test [36]. The last result thus suggests that practicing an exergame might positively influence school achievement beyond the area(s) that this exergame targets, which requires further investigation as such a possibility would be of great pedagogical interest.

This result might be due to the influence of exergaming on executive functions reported in the literature (e.g., [13,37]), as these functions include working memory, attentional flexibility, inhibitory control, and higher-level functions such as reasoning, planning, and problem-solving [38]. However, the explanation seems insufficient, as meta-analyses found that training a cognitive function such as working memory generally leads to progress only in tasks similar to those used in the training [39,40]. Another explanation might lie in the development, thanks to exergaming, of spatial ability, that is, a component of intellectual ability [41] and a predictor of math achievement [42]. A meta-analysis found a correlation between video game skill and spatial ability but no training influence of video game playing on spatial ability [43]. However, another meta-analysis found that spatial ability may be improved by training, with possible transfer effects [44]. Interestingly, studies found that the practice of physical activities in which the processing of spatial information is decisive (e.g., wrestling [45] and dance [46]) may improve mental rotation, that is, a component of spatial ability that allows one to rotate the mental image of an object [47,48]. Other studies showed that mental rotation training may positively influence math achievement (e.g., [49]). More results suggested the existence of links among mental rotation, general motor coordination, and math achievement, particularly in arithmetic [50-52].

Objectives

Based on the literature, our study aimed to determine whether practicing a dance-based exergame, with no overt math content, might positively influence mental rotation efficiency, general motor coordination, and math achievement in adolescent students.

This study differed from previous studies that examined whether exergames based on math problems and ball-throwing may favor math achievement, physical activity and ball-throwing accuracy [34,35]. Instead, our study focused on dance-based exergaming as potentially practiced during physical education (PE) lessons, but also during school periods without formal teaching, or as part of the preparation for a school event. This aimed to examine whether such practice may favor school achievement, as suggested by a previous study that showed a positive influence of exergaming based on aerobic dance on the performance of both an endurance run and a math test [36]. Compared with this study, our study had the distinction of focusing on a dance-based exergame selected as being well-suited to train mental rotation and whose practice was organized to scaffold this training.

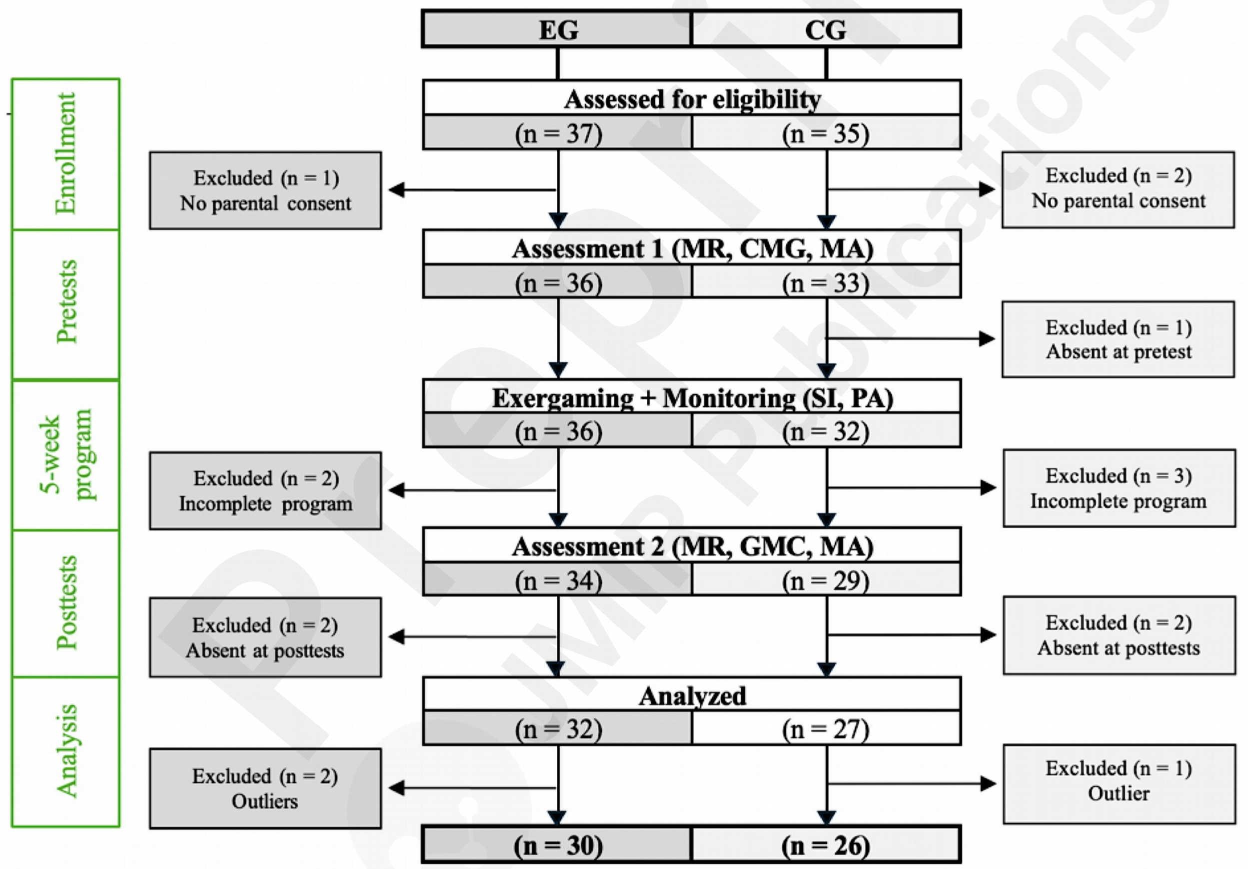
The main objective of this study was to determine the influence of this practice on mental rotation efficiency, general motor coordination, and math achievement in an experimental group (EG). This was done by comparison with a control group (CG) involved in exergaming based on precision ball throwing, using a pretest-posttest design. Students' intensity levels of physical activity during exergaming and the situational interest [53] that this practice generated in them were also measured to monitor their involvement.

Methods

Population

This study focused on two groups, EG and CG, composed of 13-16-year-old students from a secondary school based in Switzerland (canton of Vaud). Figure 1 shows the different stages involved in setting up the groups.

Figure 1. Study flow chart.



Assessments 1 and 2 targeted mental rotation (MR), general motor coordination (GMC), and math achievement (MA). During exergaming sessions, situational interest (SI), and intensity levels of physical activity (PA) were also monitored.

Based on preliminary data, a sample size calculation, using the "pwr" package in R, indicated that 21 participants per group would be required to achieve 90% power (α=.05, effect size of 0.5) to detect differences in the primary outcomes of the study. We constituted EG from two classes of the school where the experiment took place, and CG, from two other classes of this school. In the enrollment stage, 72 students were eligible to participate to the study, 37 as potential EG subjects, and 35, as potential CG subjects (Figure 1). These numbers decreased as the study progressed through the pretests, exergaming, posttests, and analysis phases (Figure 1). Finally, 56 students (27 girls and 29 boys) participated in the entire study; EG consisted of 30 students (15 girls and 15 boys) with a mean age of 14.0 (SD 0.7) years, and CG, of 26 students (12 girls and 14 boys) with a mean age of 14.2 (SD 0.9) years.

Two qualified PE teachers, with experience in teaching (10 years) and familiarity with their school's Lü exergaming system, participated in the study. One was the regular PE teacher for the two classes composing EG, and the other for the two classes composing CG. These teachers, as well as the EG and CG students, were informed of the main lines of the study but were left unaware of any expected result.

Ethical considerations

In accordance with local procedure, the project for this pilot interventional study was submitted to the Research Coordination Committee of the host university, based in Switzerland (canton of Vaud). This committee approved the project without requiring further submission to the Cantonal Commission for Ethics in Human Research. Subsequently, this project has been integrated into the university's Research Project Repository.

We also obtained official authorization to implement the study in schools located in the canton of Vaud and selected one secondary school for the study due to its exergaming facilities. We presented the project to the school's headteacher, who agreed to its implementation. The teachers involved in the experiment, the parents of the students, and the students completed written informed consent gathered prior to data collection, which gave them the option to withdraw their consent at any time. The data was anonymized and stored on a secure university computer.

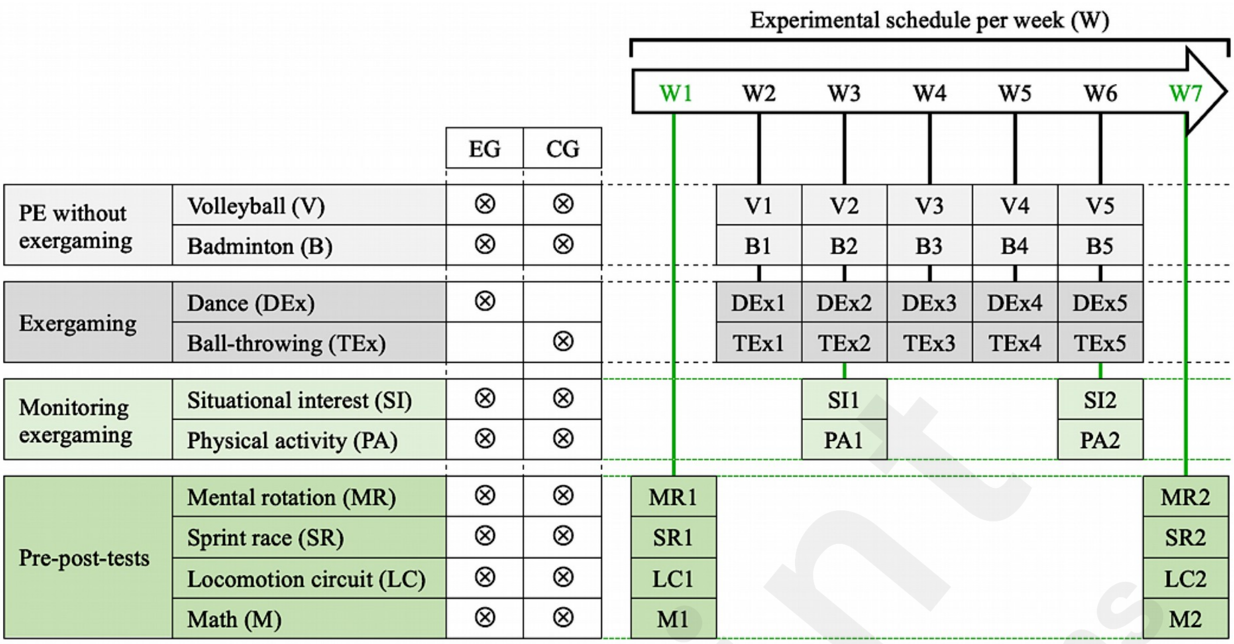
Experimental design

The sequences of exergaming, based on dance (DEx) in EG and precision ball-throwing (TEx) in CG, were implemented for five weeks during the regular PE timetable of the classes involved in the experiment. The participants attended two weekly PE lessons: one 90-minute lesson ("two-period lesson") and one 45-minute lesson ("one-period lesson"). Only the first period of each two-period lesson differed between EG and CG, with DEx sessions in EG and TEx sessions in CG. No student declared previous experience of the exergames practiced during these sequences. Both EG and CG practiced badminton during the second period of each two-period lesson and volleyball during each one-period lesson (Figure 2).

The same experimenters observed each session of DEx and TEx to check whether the teacher had implemented it as planned. The intensity levels of the EG and CG subjects' physical activity were also measured to check whether these were in line with the respective exergaming demands (Figure 2). This also allowed an estimation of the exergaming contribution to the moderate-to-vigorous physical activity (MVPA) recommended daily by the World Health Organization [54]. Measurements were done during sessions 3 and 5.

The experimenters monitored physical activity, as in previous studies (e.g., [55]), during the sessions at the end of which situational interest was assessed to control for possible differences between EG and CG likely to have influenced activity during exergaming (Figure 2). These sessions were chosen to avoid novelty bias (session 3) and allow time for possible evolution of situational interest (session 5, i.e., the last of DEx and TEx), as in previous studies (e.g., [35]).

Figure 2. Experimental design.



The students completed pretests during the week preceding the beginning of DEx and TEx and posttests during the week posterior to DEx and TEx. During both pretests and posttests, EG and CG performed a mental rotation test, a sprint race and a locomotion circuit used to assess general motor coordination, and math tests. EG and CG subjects performed mental rotation tests and math tests at the beginning of two separate math lessons. These subjects also performed the sprint race during the one-period PE lesson, and the locomotion circuit, during the two-period PE lesson. The experimenters also asked science and math teachers in classes of the EG and CG subjects not to provide any specific training on mental rotation and the mathematical content covered in the pretests and posttests during the experiment.

Exergaming system

The teachers participating in the study implemented DEx and TEx using a Lü Üno system, that is, an audiovisual infrastructure devoted to exergames practice and coming with gaming applications. In this system, the so-called “heart” module (comprising a PC computer with a webcam activated by remote control) is connected to an image projection module, a light and sound module, and a camera module for motion detection, for example, to detect the contact of a ball with the wall serving as projection screen (Figure 3).

Figure 3. Overview of the Lü Üno system.

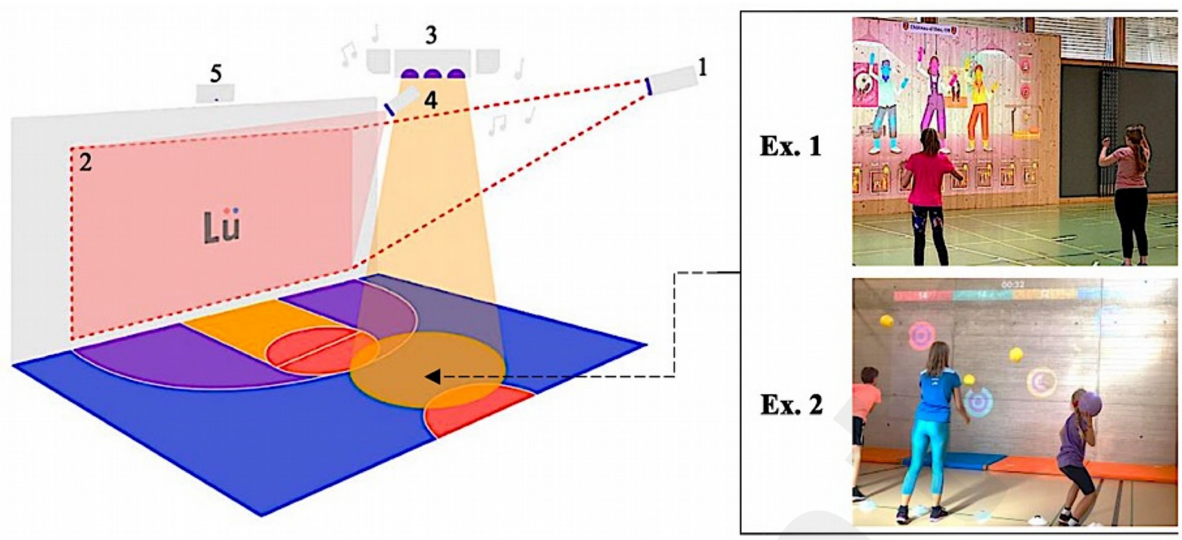


Figure 3. shows a drawing of the Lü® Üno system, i.e., a single wall configuration mounted to the ceil of a gymnasium, with: 1. High-definition laser projection (5200 lumens), 2. Image (6m x 3m), 3. Multicolored LED lighting system with moving lights and sound system with dual speakers (2400 Watts), 4. Movement detection camera allowing interaction with the projected images, and 5. Internal computer with a webcam. Ex. 1 and Ex. 2 show, as examples, photographs of exergames practice during the experiment, with: Grööve (Ex. 1), during which the experimental subjects reproduced dance movements shown by avatars, and Target (Ex. 2), during which the control subjects threw balls to hit targets.

Overview of the exergaming sequences content, sessions design, and preparation

Exergaming sequences in EG (DEx) and CG (TEx) included no overt math content. DEx required different types of locomotion and interlimb coordination, while TEx mainly required catching and throwing a ball in addition to walking and running. Mental rotation was significantly required during DEx, but its use was not relevant during TEx.

DEx and TEx sessions have been designed separately, each by a group including the researchers and the PE teacher who would teach the sequence (either to EG, or to CG). Prior to the experiment, each sequence was tested with other students than those forming EG and CG. This enabled the teachers involved in the study to perfect their use of the Lü Üno system, as DEx and TEx included elements (content, practice options) that they needed to explore further. This also led to adjusting the sequences for subsequent implementation.

Dance-based exergaming in EG

During DEx, EG practiced the exergame Grööve (Figure 3). Grööve leads to practice various dancing steps that drawings indicate and avatars demonstrate. Grööve also allows one to progressively learn an entire dance using different practice modalities (Figure 4). The choice of this application was in line with the local PE program (“CM32: Develop one's coordination skills and use one’s own body as a means of expression and communication”).

EG practiced Grööve with the explicit aim of learning a dance based on a song including four verses and a chorus. The EG subjects had to learn the dance by observing and imitating avatars’ movements (Figures 3 and 4). Sessions 1, 2, and 3 focused respectively on the first and second verses, the refrain, and the third and fourth verses, while sessions 4 and 5 were devoted to reviewing the entire dance (see: Multimedia Appendix 1). During sessions 1 to 3, the teacher organized movement learning using part practice [56] and progressively combining the learned parts; during sessions 4 to 5, the subjects reviewed the dance part by part and then entirely, leading to whole practice [56]. Consequently, the content of the sessions varied from one session to another, while ensuring continuity and progressivity in the learning. The teacher also used available options on Grööve (Figure 4) to allow progressive learning from lessons 1 to 3, as well as repetition under facilitating conditions and in final conditions during lessons 4 and 5 respectively (see: Multimedia Appendix 1).

Figure 4. Using the exergame Grööve.

The application Grööve allows to practice part of a dance, as well as the entire dance, reproducing movements demonstrated by avatars and indicated by drawings. The screenshot shows an example of movements included in the dance learned during the experiment, that were visualizable on a screen. The available options to adapt the practice difficulty to the subjects are also shown; these allowed to control the movements' speed (x1.00, x0.75, or x0.50) and/or the sound played (metronome only, metronome and music, or music only). The application also allows to pause the video ("Pause" button) and to save the progress of the subjects learning a dance ("Mastered" button).

Each part of the dance was largely composed of asymmetric movements that avatars showed facing the EG subjects; however, the avatars were also turning, so that the EG subjects were seeing them in profile (see: Multimedia Appendix 1). Thus, mental rotation was useful to observe and imitate the avatars' movements. However, it was possible to imitate correctly *part* of these movements without using mental rotation. For example, when the subjects viewed an avatar from the front, arms uncrossed, they could imitate an arm elevation seen on their left by deciding, without using mental rotation, to elevate their own right arm.

Thus, to maximize the use of mental rotation, the teacher had to instruct the EG subjects to imagine themselves dancing in the position of one of the avatars facing them, that is, to rotate mentally their own body to get into this position. The teacher had to give this instruction before each dancing phase, to reiterate it during learning, and when providing feedback. Each session, the teacher had also to film the dance movements of the EG subjects, with the Lü camera used facing them (Figure 3). At the end of the session, the teacher had to use the videos for formative evaluation and to train the subjects to analyze freeze-frames with the same instruction as when imitating an avatar (e.g., to determine which arm of the viewed subject was outstretched).

Exergaming based on precision ball-throwing in CG

During TEx, exergaming in CG was based on precision ball-throwing (for an example, see: Figure 3), which was compliant with the local PE program ("CM32: Coordination training […] using balls").
The teacher implemented TEx using eight Lü applications, each leading to throwing a ball at a target, in addition to catching it and performing simple walk or run locomotion (see: Multimedia Appendix 2). These applications were: (1) Target (throw a ball at a circular target, with the target location

changing automatically as the game progresses), (2) Galactic (throw a ball at asteroids to protect a spaceship), (3) Relé (relay race with a run to reach a floor line, a ball-throw at the team zone on the screen, then a ball catch to throw it to a partner), (4) Spörts (perform basketball shots at a virtual basket), (5) Germ (throw a ball to create obstacles preventing a virus to reach own zone and allowing to direct this virus to the adverse zone), (6) Vïka (throw a ball at targets to answer questions, then propel a boat towards a village, and protect villagers from a monster), (7) Lüvia (puzzle solving: throw a ball at the correct answer displayed on the screen among other possible answers), (8) Brüsh (throw a ball at candy before it hits an avatar's teeth, while avoiding the floss heading toward the avatar).

Throughout TEx, the common thread in terms of learning consisted in practicing precision ball-throwing. On this basis, the experimenters and the teacher designed the sessions to ensure a mix of continuity, variety, and progressivity in practice. Each session involved the use of three of the applications described above in the following chronological order: Target, Galactic, and Relé during session 1, Target, Galactic, and Spörts during session 2, Germ, Vikä, and Relé during session 3, Lüvia, Brüsh, and Spörts during session 4, Lüvia, Spörts, and Vikä during session 5. In addition to this mix of novelty and reuse in applications from one session to another, the teacher initially had to adjust the task requirements to suit the subjects' capacities, then gradually increase these requirements, using the options available for each application. For example, the subjects had to play Target with targets shown in the same screen column and then scattered across the entire screen (see: Multimedia Appendix 2).

Volleyball and badminton sequences

During the experiment, EG and CG separately took part in the same weekly 45-minute badminton and volleyball lessons (Figure 2). Each lesson began with a conventional warm-up (running, stretching, and muscle strengthening), followed by tasks focused on a sport-specific technique, and then regular matches. The content of the lessons was in line with the local PE program ("CM34: Master basic sports techniques, adapt to the game situation").

Measurements

Monitoring intensity levels of physical activity and situational interest

The experimenters conducted a non-instrumented observation of each DEx and TEx session implemented to enable comparison between the observed session and the planned session regarding content, teacher intervention, and subject activity.

During sessions 3 and 5 of DEx and TEx, the experimenters also measured the intensity levels of physical activity achieved by each subject using hip-worn GT3X+ accelerometers (Actigraph Co.; Pensacola, FL, USA), providing a receivable estimation of physical activity in free-living conditions [57]. The accelerometer data were processed using ActiLife6. This led to converting the data into activity counts that were summed and recorded using a specific time interval known as an "epoch" (selectable duration from 5 seconds to 1 minute). The selected epoch was 5 seconds, as the study was focused on acute and intermittent exercise bouts. The examined variables were (1) the moderate and vigorous intensity levels, expressed in seconds and percentage of time activity, and (2) MVPA, expressed similarly to (1). Given the exergaming characteristics in DEx and TEx described above, we expected EG to be more involved than CG in vigorous-intensity activity, and CG more involved than EG in moderate-intensity activity, as the musical tempo in DEx was to be increased during session 3 and remain at peak in session 5, whereas no such activity peaks were planned in TEx.

Directly after sessions 3 and 5, the experimenters assessed the situational interest of each subject using the French situational interest questionnaire [58] that contains three factors: (1) triggered situational interest (participant's perception of the game demanding full attention), (2) maintained situational interest feeling (to what extent the activities were found enjoyable), and (3) maintained situational interest value (importance allocated to success during the game). To complete the questionnaire, the subjects had to rate statements on a five-point Likert scale (see: Multimedia Appendix 3); for each factor, this led to scores ranging from 1 (lowest possible score) to 5 (highest possible score).

Pretests and posttests

The EG and CG subjects completed the French version [59] of Vandenberg and Kuse's mental rotations test [60] based on a comparison of images of geometrical structures made of 10 cubes (see: Multimedia Appendix 4), the scores ranging from 0 to 40 points, with 40 corresponding to a perfect performance.

These subjects also performed a locomotion circuit called the Harre circuit test in the literature (e.g., [61]) to assess general motor coordination [62], with reaction to an audible signal, a forward roll, running phases with direction changes, and phases with jumping over a bench, then crawling under it (see: Multimedia Appendix 4). In line with previous studies [52,63], a sprint race (20 meters) was performed separately to control for the influence of sprinting capacities on the circuit performance. The performance of the locomotion circuit and of the sprint race were timed using the same timing system (Race link Racing System; Brower Timing Systems, Draper, UT, USA).

Moreover, the subjects performed two separate paper-and-pencil series of quantity comparisons, based on a previous study [64] (see: Multimedia Appendix 4), that is, a series of comparisons between two sets of points and a series of comparisons between two single-digit numbers. The subjects also performed four separate paper-and-pencil series of mental calculations, based on a previous study [65] (see: Multimedia Appendix 4), that is, series of simple additions (two single-digit numbers), complex additions (three two-digit numbers), simple multiplication (two single-digit numbers), and complex multiplication (a two-digit number and a single-digit number). For each task series listed above, we considered the total number of processed items, the number of correct results, and the error rate.

Statistical analyses

Data were analyzed using IBM SPSS Statistics, version 30.0.0.0 (171). The normality of the numerical variables was preliminarily checked, and the internal reliability of the situational interest scales was evaluated using Cronbach α coefficients.

MANOVA tests were performed to compare the intensity levels of physical activity in EG and CG during sessions 3 and 5 of DEx and TEx. The scores for each intensity level considered were specified as dependent variables and the group condition (EG vs CG) as fixed factor. Similarly, MANOVA tests were done to examine possible differences between EG and CG in scores for each of the three situational interest factors measured after sessions 3 and 5.

For each variable measured at pretest and posttest, ANCOVA tests were performed using a GLM approach [66]. The model included basically the posttest score as the dependent variable, the group (EG vs CG) as fixed factor, and the pretest score as covariate; in the event of between-group difference regarding a situational interest variable, it was planned to add the variable as a covariate. Beyond data normality, variance homogeneity, heteroskedasticity, and regression homogeneity were checked; on such basis, ANCOVA was computed either on untransformed data or on ranks, using the same method for the computations [66,67].

For all the analyses, partial eta squared (η_p^2) provided an index of effect size. Contrast analyses were applied in case of significant results.

Results

Intensity levels of physical activity and situational interest

The observation of each DEx and TEx session led to conclude that the sessions were taught as planned and that the students completed the exergaming tasks. Such observation was supplemented by the results of analyses of physical activity intensity levels and situational interest during sessions 3 and 5.

The data relating to physical activity intensity levels were normally distributed (skewness and kurtosis values ranging from –.64 to .79, SE .32, and –.58 to 2.56, SE .63, respectively). For each MANOVA (Table 1), Pillar's Trace values ranged from $F_{3,52}$=10.44 to $F_{3,52}$=63.63 (P<.001).

Table 1. Results of MANOVA tests for physical activity intensity levels

	EG[a] (n=30) Mean (SD)	CG[b] (n=26) Mean (SD)	MANOVA tests *F* test (df)	*P* value	η_p^2	Contrasts
S3sec[c]						
Moderate	739.7 (122.7)	1060.8 (154.4)	75.10 (1,54)	<.001	.58	EG < CG
Vigorous	336.7 (82.2)	283.6 (139.42)	3.10 (1,54)	.08	.05	
MVPA[d]	1180.7 (173.5)	1419.2 (290.3)	14.16 (1,54)	<.001	.21	EG < CG
S3%[e]						
Moderate	35.9 (5.3)	42.0 (5.5)	17.75 (1,54)	<.001	.25	EG < CG
Vigorous	16.4 (4.0)	12.5 (5.9)	8.46 (1,54)	.005	.13	EG > CG
MVPA	57.4 (8.0)	56.1 (3.3)	.30 (1,54)	.59	.005	
S5sec[f]						
Moderate	724.7 (102.5)	1035.0 (164.3)	73.94 (1,54)	<.001	.58	EG < CG
Vigorous	322.7 (63.3)	221.0 (115.3)	17.34 (1,54)	<.001	.24	EG > CG
MVPA	1189.3 (154.1)	1311.9 (291.7)	4.01 (1,54)	.05	.07	
S5%[g]						
Moderate	32.1 (.04)	40.9 (5.6)	42.01 (1,54)	<.001	.44	EG < CG
Vigorous	14.3 (2.9)	10.0 (5.5)	14.72 (1,54)	<.001	.21	EG > CG
MVPA	52.8 (6.9)	51.7 (10.3)	.17 (1,54)	.68	.003	

[a]EG: experimental group
[b]CG: control group
[c]S3sec: intensity levels of physical activity in seconds during session 3
[d]MVPA: moderate-to-vigorous physical activity
[e]S3%: intensity levels of physical activity in percentage of the total physical activity time during session 3
[f]S5sec: intensity levels of physical activity in seconds during session 5
[g]S5%: intensity levels of physical activity in percentage of the total physical activity time during session 5

On average, during session 3, the EG subjects spent 1180.7 (SD 173.5) seconds in MVPA that is, 57% of total physical activity time, and the CG subjects, 1419.2 (SD 290.3), that is, 56% of total physical activity time. During session 5, the values were 1189.3 (SD 154.1) and 53% in EG, 1311.9 (SD 291.7) and 52% in CG (Table 1).

GC had more MVPA time than EG in sessions 3 (P<.001) and 5 (P=.05), but no between-group difference was found when considering MVPA as a percentage of total physical activity time in sessions 3 (P=.59) and 5 (P=.68). As expected, MVPA relied on: (1) significantly higher moderate-intensity values in CG than in EG, in seconds and percentage of total physical activity time during sessions 3 and 5 (P<.001), and (2) higher vigorous-intensity values in EG than in CG, in seconds and percentage of total physical activity time during sessions 3 and 5, with significant differences (P<.001), expect for values in seconds during session 3 (P=.08).

On the other hand, data on situational interest in sessions 3 and 5 were normally distributed (skewness and kurtosis values from –.50 to .47, SE .32, and from –1.19 to –.83, SE .63, respectively). In addition, the Cronbach α were good for each situational interest factor measured after sessions 3 (from .89 to .92) and 5 (from .90 to .92). Results of MANOVA tests reached statistical significance for session 5 (Pillar's trace with $F_{3,52}$=3.93, P=.01), but not session 3 ($F_{3,52}$=1.09, P=.36), due to higher score for triggered situational interest in EG than in CG (P=.004) in session 5 (Table 2). Consequently, triggered situational interest during session 5 was added as a covariate to perform ANCOVA tests in further analyses.

Table 2. Results of MANOVA tests for situational interest

	EG[a] (n=30) Mean (SD)	CG[b] (n=26) Mean (SD)	MANOVA tests F test (df)	P value	η_p^2	Contrasts
SI-S3[c]						
TSI[d]	3.52 (1.39)	2.89 (1.21)	3.23 (1,54)	.08	.06	
MSIF[e]	2.63 (1.17)	2.21 (1.05)	1.98 (1,54)	.16	.03	
MSIV[f]	2.59 (1.13)	2.16 (1.10)	2.04 (1,54)	.16	.04	
SI-S5[g]						
TSI	3.49 (1.23)	2.47 (1.29)	9.15 (1,54)	.004	.14	EG > CG
MSIF	2.34 (1.05)	2.02 (1.12)	1.23 (1,54)	.27	.02	
MSIV	2.42 (1.10)	2.08 (1.14)	1.34 (1,54)	.25	.02	

[a]EG: experimental group
[b]CG: control group
[c]SI-S3: situational interest in session 3
[d]TSI: triggered SI
[e]MSIF: maintained SI feeling
[f]MSIV: maintained SI value
[g]SI-S5: SI in session 5

Pretests, posttests, and exergaming influence

ANCOVAs were performed on ranks for the total number and the number of correct comparisons of dot ensembles performed (heteroskedasticity test with $F_{1,54}$=4.88, P=.03, and $F_{1,54}$=4.18, P=.046), all data series for number comparison (kurtosis values from 2.60 to 4.90, SE .63), the total number of calculations in simple addition (Levene's test with $F_{1,54}$=7.94, P<.001), error rate in simple (kurtosis values of 3.02 and 14.82, SE.63) and complex (Levene's test with $F_{1,54}$=18.72, P<.001) additions, and in simple multiplication (kurtosis values of 3.26 and 15.50, SE.63). Untransformed data were used in any other case. No significant regression homogeneity issue was found (results ranging from $F_{1,50}$=.003, P=.95, to $F_{1,50}$=3.05, P=.08).

The results showed that EG had a statistically significant advantage over CG regarding the Vandenberg and Kuse mental rotations test scores (P=.016), the number of correct results of simple additions (P=.006), and the error rate in complex additions (P=.005). No other significant differences were found, either in terms of additions, or in measurements relating to the sprint race, the locomotion circuit, quantity comparisons, or multiplications (Table 3).

Table 3. Results of ANCOVA tests

	Pretests, mean (SD)		Posttests, mean (SD)		ANCOVA tests			Contrast
	EG[a] (n=30)	CG[b] (n=26)	EG (n=30)	CG (n=26)	*F* test (df)	*P* value	η_p^2	
VMRT[c]								
Score	18.40 (7.98)	13.77 (7.51)	22.23 (8.95)	13.88 (8.35)	6.17 (1,52)	.016	.11	EG>CG
GMC[d]								
Sprint	3.60 (.41)	3.62 (.34)	3.65 (.30)	3.63 (.38)	.18 (1,52)	.68	.003	
LC[e]	22.41 (4.15)	22.42 (3.44)	21.72 (4.39)	21.20 (3.41)	.86 (1,52)	.36	.02	
DC[f]								
N[g] (r[h])	59.43 (9.03)	60.81 (7.27)	64.63 (8.76)	67.23 (6.22)	.66 (1,52)	.42	.01	
C[i] (r)	55.20 (5.23)	56.85 (5.26)	58.73 (8.14)	61.27 (4.57)	.01(1,52)	.93	.0001	
ER[j]	6.23 (7.03)	6.15 (4.41)	8.92 (7.36)	8.61 (4.24)	.08 (1,52)	.77	.002	
NC[k]								
N (r)	65.53 (7.08)	66.15 (6.42)	68.96 (6.10)	68.81 (5.51)	.13 (1,52)	.71	.003	
C (r)	64.97 (6.90)	65.08 (6.52)	67.83 (5.80)	67.92 (5.51)	2.11 (1,52)	.15	.04	
ER (r)	.83 (1.24)	1.63 (2.21)	1.65 (1.32)	1.29 (1.20)	2.17 (1,52)	.15	.04	
SA[l]								
N (r)	39.47 (11.08)	42.92 (12.59)	47.30 (13.65)	45.27 (11.22)	3.11 (1,52)	.08	.06	
C	38.97 (11.21)	41.35 (12.19)	46.47 (13.33)	43.46 (12.21)	8.26 (1,52)	.006	.14	EG>CG
ER (r)	1.43 (2.99)	3.53 (3.88)	1.72 (2.46)	4.63 (7.51)	1.85 (1,52)	.18	.03	
CA[m]								
N	7.90 (2.19)	7.46 (2.55)	9.07 (2.66)	8.65 (3.21)	.09 (1,52)	.76	.002	
C	6.73 (2.11)	5.42 (2.84)	8.07 (2.46)	6.35 (3.26)	1.45 (1,52)	.23	.03	
ER (r)	14.57 (16.24)	30.32 (25.50)	10.70 (10.59)	27.08 (22.93)	8.40 (1,52)	.005	.14	EG<CG
SM[n]								
N	28.60 (9.47)	33.04 (11.00)	31.63 (9.30)	35.27 (10.41)	.04 (1,52)	.85	.001	
C	27.70 (9.81)	31.31 (10.81)	30.47 (9.10)	33.19 (11.11)	.01 (1,52)	.92	.0002	
ER (r)	3.76 (5.98)	5.51 (6.07)	3.69 (4.75)	6.46 (11.15)	.01 (1,52)	.93	.0001	
CM[o]								
N	13.43 (2.61)	13.42 (3.05)	14.27 (3.05)	13.92 (2.53)	.01 (1,52)	.91	.0002	
C	12.30 (2.58)	11.85 (2.92)	12.80 (2.71)	12.31 (2.82)	.21 (1,52)	.64	.004	
ER	8.54 (8.71)	11.25 (10.54)	9.65 (9.64)	11.86(9.64)	.04 (1,52)	.84	.001	

[a]EG: experimental group
[b]CG: control group
[c]VMRT: Vandenberg and Kuse mental rotations test
[d]GMC: general motor coordination (all measurements in sec)
[e]LC: locomotion circuit (Harre circuit test)
[f]DC: comparison of dot ensembles
[g]N: total number of items performed
[h](r): ANCOVA computed on ranks
[i]C: number of correct responses
[j]ER: error rate
[k]NC: number comparison
[l]SA: simple addition
[m]CA: complex addition
[n]SM: simple multiplication
[o]CM: complex multiplication

Discussion

Principal findings

This pilot interventional study aimed to determine whether dance-based exergaming (DEx), involving mental rotation to perform different types of locomotion and interlimb coordination, may influence: (1) mental rotation efficiency, (2) general motor coordination, and (3) math achievement in an experimental group (EG) of adolescent students. This was done using a pretest-posttest design, including a control group (CG) involved in exergaming based on precision ball-throwing (TEx) and monitoring physical activity intensity levels and situational interest.

Non-instrumented observation suggested that the sessions proceeded as planned. This was corroborated by physical activity monitoring (Table 1), which also showed that MVPA timed values approached one-third (from 33% to 39%) of the daily 60 minutes recommended for beneficial effects on adolescent health [54]. This suggested that situational interest did not impede the physical activity required by DEx and TEx. Only the scores for the triggered situational interest factor in session 5 significantly differed between groups, with a higher score in EG than in CG (Table 2). ANCOVAs were performed controlling for this variable; the results are discussed below.

Exergaming influence on mental rotation test scores

DEx was likely to elicit mental rotation training in EG, whereas mental rotation was not relevant during TEx in CG. The advantage for EG over CG regarding mental rotation found, once DEx and TEx were completed, may thus be due to mental rotation training in EG during DEx. This influence of dance-based exergaming on mental rotation in adolescents is consistent with the results of previous studies showing the influence on mental rotation of exergaming based on leg movements, but in adult patients with chronic stroke [68], and of certain physical activities (e.g., wrestling vs endurance running) in healthy students, but which were practiced outside the exergaming framework [45].

Furthermore, in the present study, dance-based exergaming influence on mental rotation was found using a test [60] with tasks and stimuli (geometrical structures to be compared to a reference) different from mental rotation training tasks and stimuli (images of avatars and humans to be related to one’s own body). This supports that mental rotation training may elicit transfer to tasks and stimuli different from those used for training. Such result, in line with those of previous studies obtained without physical activity during mental rotation training, contributes to fuel a long-standing and still running debate in the literature [69].

Exergaming influence on general motor coordination

This study showed no significant difference regarding general motor coordination between EG and CG, once DEx and TEx were completed (Table 3). No difference was expected for sprinting, as neither DEx nor TEx trained sprinting capacities. The timed performance was 3.60 (SD 0.41) seconds at pretest and 3.65 (SD 0.20) at posttest in EG, and the values were 3.62 (SD 0.34) and 3.63 (SD 0.38) in CG. This suggests that EG and CG had similar and stable potentiality to achieve the run parts of the locomotion circuit used to assess general motor coordination. Thus, DEx and TEx showed similar influence on the performance of the other parts of the circuit, and the performance improved on average from 22.41 (SD 4.15) to 21.72 (SD 4.39) seconds in EG (3% improvement) and from 22.42 (SD 3.44) to 21.20 (SD 3.41) seconds in CG (5% improvement).

It remains that these variations did not lead to significant between-group differences in terms of ANCOVA results, while movements requirements differed between DEx and TEx. Considering that general motor coordination is a multidimensional construct [70], both DEx and TEx might have developed abilities influential on the performance of the locomotion circuit used for assessment. For example, DEx influence on mental rotation might have impacted this performance [52], but TEx might have developed other abilities having such an impact, notably linked to displacements for catching a ball. On such basis, further research remains needed to clarify whether, and under which conditions, exergaming might influence general motor coordination.

Exergaming influence on math achievement

A previous study reported the positive influence of exergaming based on aerobic dance on the global score of a test assessing math achievement [36]. Our results confirmed such influence of dance-based exergaming when compared with exergaming based on precision ball-throwing. However, this influence was found limited to peculiar mathematical tasks (Table 3). No significant difference between EG and CG was found regarding the “number tasks” [71] of quantity comparison (i.e., with numbers and quantities but without requirements in formal calculation). On the other hand, mixed results were obtained regarding the “calculation tasks” [71] (i.e., requiring the application of operation rules to numbers), with: (1) no significant between-group differences in multiplications, and (2) a significant advantage for EG over CG regarding the number of simple additions correctly performed and the error rate in complex additions. Calculation of simple additions was thus faster in EG than in CG, without detrimental effect on the error rate, and the error rate in complex additions was lower in EG than CG, without detrimental effect on calculation speed.

According to the literature [72], this advantage for EG might be limited to tasks primarily requiring procedural strategies for calculating, rather than strategies for retrieving memorized results. In support of this possibility, additions, even simple (e.g., 7+5), have been found to rely on procedural strategies more than simple multiplications (e.g., 7x5), mainly based on retrieval strategies [72]. This explanation appears plausible though we found no differences between EG and CG in terms of complex multiplications. Such multiplications involve retrieval strategies, combined with calculation procedures (e.g., for adding the retrieved results of 2x7 and of 10x7, when calculating 12x7). Although EG had an advantage over CG in additions (Table 3), this might have elicited a weak impact on efficacy in complex multiplications. Overall, this is also consistent with the advantage in mental rotation efficiency for EG over CG found in our study (Table 3). Indeed, studies showed that mental rotation may improve calculation efficiency by promoting appropriate access to a representation of numbers as a mental number line (e.g., [73]), particularly involved during addition, but not multiplication (e.g., [74]).

Limitations

Although our study helps to fill a gap in the literature concerning the possible influence of exergaming on academic performance, it is not without its limitations. One limitation is linked to the implementation of scientific research in a school environment. Notably, this did not allow us to allocate students randomly between EG and CG. Possible generalization of the results should also be questioned, especially as these results might depend on features of the exergaming sequences implemented, of the school of implementation, and of the students involved in the sequences. Confirmation of our results could also be sought using larger samples and longer sequences than in this study.

Perspectives

The results of this study encourage to clarify whether mental rotation training through exergaming may influence math achievement. These results also encourage further investigation to determine if the influence of exergaming on the performance of arithmetical tasks is limited to tasks requiring procedural strategies for calculation. This also raises the question of whether such influence might depend on age, gender, or math experience. Analysis of task repetition and participants’ experience when exergaming might be useful in clarifying these points. Moreover, this study does not allow conclusions on exergaming influence on general motor coordination; the results encourage further research to clarify this influence and its potential links with mental rotation training during exergaming. It would also be of interest to assess the potential added value of specific exergaming features (e.g., avatar demonstration, or options for managing exercise variety and progression) in achieving the effects observed in our study. Teacher interventions directly linked to such features could complementarily be considered. This assessment might be done by comparison with a conventional physical activity.

Conclusion

For the first time, to our knowledge, our study provides support for the possibility that the same dance-based exergaming sequence may have a positive influence, in the same adolescent students, on performance in a mental rotation test and in tasks of addition. These results encourage complementary investigations, especially to delimit the possible influence of practicing an exergame on math achievement and determine to what extent such influence might depend on mental rotation training, and possibly motor coordination training, during this practice. However, the present results suggest the relevance of including exergames at school to promote both PE and math achievement.

Acknowledgements
The authors would like to thank all the students and teachers who took part in the study.

Data availability
The datasets analyzed during this study are available from the corresponding author on reasonable request.

Funding statement
This work was supported by the Reserve and Innovation Fund of the University of Teacher Education (HEP-VD), 1007 Lausanne, Switzerland (grant number 10_FRI_A21_Fargier).

Authors' contributions
PF contributed to conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, supervision, and writing (original draft, review and editing). VC contributed to formal analysis, investigation, methodology, writing (original draft, review and editing). VLK and CR contributed to conceptualization, funding acquisition, investigation, and writing (review and editing).

Conflicts of interest
None declared.

References
1. Quwaider M, Alabed A, Duwairi R. The impact of video games on the players behaviors: a survey. Procedia Comput Sci. 2019;151:575-582. [doi: 10.1016/j.procs.2019.04.077]
2. Granic I, Lobel A, Engels, RCME. The benefits of playing video games. Am Psychol. Jan, 2014;69(1):66-78. [doi: 10.1037/a0034857] [PMID: 24295515]
3. Cole C, Parada RH, Mackenzie E. A scoping review of video games and learning in secondary classrooms. J Res Technol Educ. Mar 13, 2023;56(5):544-577. [doi: 10.1080/15391523.2023.2186546]
4. Martinez L, Gimenes M, Lambert E. Entertainment video games for academic learning: a systematic review. J Educ Comput Res. Jan 12, 2022;60(5):1083-1109. [doi: 10.1177/07356331211053848]
5. Martinez L, Gimenes L, Lambert E. Video games and board games: effects of playing practice on cognition. PLoS One. Mar 27, 2023;18(3):e0283654. [doi: 10.1371/journal.pone.0283654] [PMID: 36972271]
6. Brandl LC, Schrader A. Serious games in higher education in the transforming process to education 4.0 – Systematized Review. Educ Sci. Mar 7, 2024;14(3):281. [doi: 10.3390/educsci14030281]
7. Adcock M, Fankhauser M, Post J, et al. Effects of an in-home multicomponent exergame training on physical functions, cognition, and brain volume of older adults: a randomized

controlled trial. Front Med. Jan 28, 2020;6:321. [doi: 10.3389/fmed.2019.00321] [PMID: 32047751]
8. Barbosa A, Whiting S, Simmonds P, Scotini Moreno RS, Mendes R, Breda J. Physical activity and academic achievement: an umbrella review. Int J Environ Res Public Health. Aug 17, 2020;17(16):5972. [doi: 10.3390/ijerph17165972] [PMID: 32824593]
9. Prot S, McDonald KA, Anderson CA, Gentile DA. Video games: good, bad, or other? Pediatr Clin North Am. Jun, 2012;59(3):647-658. [doi: 10.1016/j.pcl.2012.03.016] [PMID: 22643171]
10. Andrade A, Correia CK, da Cruz WM, Bevilacqua GG. Acute effect of exergames on children's mood states during physical education classes. Games Health J. Aug 2, 2019;8(4):250-256. [doi: 10.1089/g4h.2018.0083] [PMID: 30730230]
11. Gao Z, Chen S. Are field-based exergames useful in preventing childhood obesity? A systematic review. Obes Rev. Aug, 2014;15(8):676-691. [doi: 10.1111/obr.12164] [PMID: 24602072]
12. Marques LM, Uchida PM, Barbosa SP. The impact of exergames on emotional experience: a systematic review. Front Public Health. Sep 7, 2023;11:1209520. [doi: 10.3389/fpubh.2023.1209520] [PMID: 37744509]
13. Kolovelonis A, Papastergiou M, Samara E, Goudas M. Acute effects of exergaming on students' executive functions and situational interest in elementary physical education. Int. J. Environ. Res. Public Health. Jan 20, 2023;20(3):1902. [doi: 10.3390/ijerph20031902] [PMID: 36767269]
14. Pérez-Jorge D, Martínez-Murciano MC, Contreras-Madrid AI, Alonso-Rodríguez I. The relationship between gamified physical exercise and mental health in adolescence: an example of open innovation in gamified learning. Healthcare. Jan 5, 2024;12(2):124. [doi: 10.3390/healthcare12020124] [PMID: 38255013]
15. Sun H. Exergaming impact on physical activity and interest in elementary school children. Res Q Exerc Sport. Jun, 2012;83(2):212-220. [doi: 10.1080/02701367.2012.10599852] [PMID: 22808707]
16. Pasco D, Roure C. Situational interest impacts college students' physical activity in a design-based bike exergame. J Sport Health Sci. Mar, 2022;11(2):172-178. [doi: 10.1016/j.jshs.2021.03.003] [PMID: 33722758]
17. Haddock B, Siegel S, Costa P, et al. Fitness assessment comparison between the "Jackie Chan action run" videogame, 1-mile run/walk, and the PACER. Games Health J. Jun, 2012;1(3):223-227. [doi: 10.1089/g4h.2012.0007] [PMID: 26193440]
18. Moholdt T, Weie S, Chorianopoulos K, Wang AI, Hagen K. Exergaming can be an innovative way of enjoyable high-intensity interval training. BMJ Open Sport Exerc Med. Jul 28, 2017;3(1): e000258. [doi: 10.1136/bmjsem-2017-000258] [PMID: 29021913]
19. Marsigliante S, My G, Mazzotta G, Muscella A. The effects of exergames on physical fitness, body composition and enjoyment in children: a six-month intervention study. Children. Sep 26, 2024;11(10):1172. [doi: 10.3390/children11101172] [PMID: 39457137]
20. Moller AC, Sousa CV, Lee KJ, Alon D, Lu AS. A comprehensive systematic review and content analysis of active video game intervention research. Digit Health. Jan-Dec, 2023;9. [doi: 10.1177/20552076231171232]
21. Ebbinghaus H. *Über das Gedächtnis: Untersuchungen zur experimentellen psychologie*. Leipzig: Dunker & Humbolt; 1885. https://home.uni-leipzig.de/wundtbriefe/wwcd/opera/ebbing/memory/GdaechtI.htm [access: July 10, 2025]
22. Musfeld P, Souza AS, Oberauer K. Repetition learning is neither a continuous nor an implicit process. Proc Natl Acad Sci USA. Apr 11, 2023;120(16):e2218042120. [doi: 10.1073/pnas.2218042120] [PMID: 37040406]

23. Liu W, Zeng N, McDonough DJ, Gao Z. Effect of active video games on healthy children’s fundamental motor skills and physical fitness: a systematic review. Int J Environ Res Public Health. Nov 9, 2020;17(21):8264. [doi: 10.3390/ijerph17218264] [PMID: 33182327]
24. Logan SW, Ross SM, Chee K. Stodden DF, Robinson LE. Fundamental motor skills: a systematic review of terminology. J Sports Sci. Apr, 2018;36(7):781-796. [doi: 10.1080/02640414.2017.1340660] [PMID: 28636423]
25. Oppici L, Stell FM, Utesch T, Woods CT, Foweather L, Rudd JR. A skill acquisition perspective on the impact of exergaming technology on foundational movement skill development in children 3-12 years: a systematic review and meta-analysis. Sports Med Open. Dec 16, 2022;8:148. [doi: 10.1186/s40798-022-00534-8] [PMID: 36525118]
26. Gao Z, Wen X, Fu Y, Lee JE, Zeng N. Motor skill competence matters in promoting physical activity and health, Biomed Res Int. Dec 24, 2021;9786368. [doi: 10.1155/2021/9786368] [PMID: 35028311]
27. Barnett LM, Lai SK, Veldman SLC, et al. Correlates of gross motor competence in children and adolescents: a systematic review and meta-analysis. Sports Med. Nov, 2016;46(11):1663-1688. [doi: 10.1007/s40279-016-0495-z] [PMID: 26894274]
28. Sousa CV, Lee K, Alon D, Sternad D, Lu AS. A systematic review and meta-analysis of the effect of active video games on postural balance. Arch Phys Med Rehabil. Apr, 2023;104(4):631-644. [doi: 10.1016/j.apmr.2023.01.002] [PMID: 36669637]
29. McGann J, Issartel J, Hederman L, Conlan O. Hop.Skip.Jump.Games: the effect of “principled” exergameplay on children's locomotor skill acquisition. Brit J Educ Technol. May, 2020;51(3):798-816. [doi: 10.1111/bjet.12886]
30. Li S, Song Y, Cai Z, Zhang Q. Are active video games useful in the development of gross motor skills among non-typically developing children? A meta-analysis. BMC Sports Sci Med Rehabil. Jul 23, 2022;14(1):140. [doi: 10.1186/s13102-022-00532-z] [PMID: 35870986]
31. Trecroci A, Cavaggioni L, Caccia R, Alberti G. Jump rope training: balance and motor coordination in preadolescent soccer players. J Sports Sci Med. Nov 24, 2015;14(4):792:798. [PMID: 26664276]
32. Daly-Smith A, Morris JL, Norris E, et al. Behaviours that prompt primary school teachers to adopt and implement physically active learning: a meta synthesis of qualitative evidence. Int J Behav Nutr Phys Act. Nov 20, 2021;18:151. [doi: 10.1186/s12966-021-01221-9] [PMID: 34801039]
33. Chalkley AE, Mandelid MB, Thurston M, et al. “Go beyond your own comfort zone and challenge yourself”: a comparison on the use of physically active learning in Norway, the Netherlands and the UK. Teach Teach Educ. Oct, 2022;118:103825. [doi: 10.1016/j.tate.2022.103825]
34. Goncalves A, Lespiau F, Briet G, et al. Exploring the use of a learning-based exergame to enhance physical literacy, soft skills, and academic learning in school-age children: pilot interventional study. JMIR Serious Games. Feb 23, 2024; 2:e53072. [doi: 10.2196/53072] [PMID: 38393767]
35. Cece V, Fargier P, Roure C, Lentillon-Kaestner V. Multidisciplinary teaching with an active video game: the effect on learning in mathematics and physical education. Technol Pedagogy Educ. Feb, 2025; 34(1):121-136. [doi: 10.1080/1475939X.2024.2407380]
36. Gao Z, Hannan P, Xiang P, Stodden DF, Valdez VE. Video game-based exercise, Latino children’s physical health, and academic achievement. Am J Prev Med. Mar, 2013;44(3 Suppl 3):S240-S246. [doi: 10.1016/j.amepre.2012.11.023] [PMID: 23415189]
37. Benzing V, Heinks T, Eggenberger N, Schmidt M. Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. PLoS One. Dec 28, 2016;11(12):e0167501. [doi: 10.1371/journal.pone.0167501] [PMID: 28030542]

38. Diamond A. Executive functions. Annu Rev Psychol. Jan, 2013;64:135-168. [doi: 10.1146/annurev-psych-113011-143750] [PMID: 23020641]
39. Melby-Lervåg M, Redick TS, Hulme C. Working memory training does not improve performance on measures of intelligence or other measures of “far-transfer”: evidence from a meta-analytic review. Perspect Psychol Sci. Jul, 2016;11(4):512-534. [doi: 10.1177/1745691616635612] [PMID: 27474138]
40. Sala G, Aksayli ND, Tatlidil KS, Tatsumi T, Gondo Y, Gobet S. Near and far transfer in cognitive training: a second-order meta-analysis. Collabra Psychol. Apr 26, 2019;5(1):18. [doi: 10.1525/collabra.203]
41. Linn MC, Petersen AC. Emergence and characterization of sex differences in spatial ability: a meta-analysis. Child Dev. Dec, 1985;56(6):1479-1498. [doi: 10.2307/1130467] [PMID: 4075870]
42. Wai J, Lubinski D, Benbow CP. Spatial ability for STEM domains: aligning over 50 years of cumulative psychological knowledge solidifies its importance. J Educ Psychol. Nov, 2009;101(4):817-835. [doi: 10.1037/a0016127]
43. Sala G, Tatlidil KS, Gobet F. Video game training does not enhance cognitive ability: a comprehensive meta-analytic investigation. Psychol Bull. Feb, 2018;144(2):111-139. [doi: 10.1037/bul0000139] [PMID: 29239631]
44. Uttal DH, Meadow NG, Tipton E, et al. The malleability of spatial skills: a meta-analysis of training studies. Psychol Bull. Mar, 2013;139(2):352-402. [doi: 10.1037/a0028446] [PMID: 22663761]
45. Moreau D, Clerc J, Mansy-Dannay A, Guerrien A. Enhancing spatial ability through sport practice. Evidence for an effect of motor training on mental rotation performance. Learn Ind Diff. May, 2012;33(2):83-88. [doi: 10.1027/1614-0001/a000075]
46. Jansen P, Kellner J, Rieder C. The improvement of mental rotation performance in second graders after creative dance training. Creat Educ. Jun, 2013;4(6):418-422. [doi: 10.4236/ce.2013.46060]
47. Shepard RN, Metzler J. Mental rotation of three-dimensional objects. Science. Feb 19, 1971;171(3972):701-703. [doi: 10.1126/science.171.3972.701] [PMID: 5540314]
48. Voyer D, Voyer S, Bryden MP. Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. Psychol Bull. Mar, 1995;117(2):250-270. [doi: 10.1037/0033-2909.117.2.250] [PMID: 7724690]
49. Hauwes ZCK, Gilligan-Lee KA, Mix KS. Effects of spatial training on mathematics performance: a meta-analysis. Dev Psychol. Jan, 2022;58(1):112-137. [doi: 10.1037/dev0001281] [PMID: 35073120]
50. Fargier P, Champely S, Massarelli R, Ammary L, Hoyek N. Modelling response time in a mental rotation task by gender, physical activity, and task features. Sci Rep. Sep 16, 2022;12:15559. [doi: 10.1038/s41598-022-19054-2] [PMID: 36114235]
51. Geertsen SS, Thomas R, Larsen MN, et al. Motor skills and exercise capacity are associated with objective measures of cognitive functions and academic performance in preadolescent children. PLoS One. Aug 25, 2016;11(8):e0161960. [doi: 10.1371/journal.pone.0161960] [PMID: 27560512]
52. Hoyek N, Champely S, Collet C, Fargier P, Guillot A. Is mental rotation ability a predictor of success for motor performance? J Cogn Dev. 2014;15(3):495-505. [doi: 10.1080/15248372.2012.760158]
53. Hidi SE, Renninger KA. The four-phase model of interest development. Educ Psychol. 2006;41(2):111-127. [doi: 10.1207/s15326985ep4102_4]
54. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. Dec, 2020;54(24):1451-1462. [doi: 10.1136/bjsports-2020-102955] [PMID: 33239350]

55. Pasco D, Roure C, Kermarrec G, Pope Z, Gao Z. The effects of a bike active video game on players' physical activity and motivation. J Sport Health Sci. Mar, 2017;6(1):25-32. [doi: 10.1016/j.jshs.2016.11.007] [PMID: 30356595]
56. Chan JSY, Luo Y, Yan JH, Cai L, Peng K. Children's age modulates the effect of part and whole practice in motor learning. Hum Mov Sci. Aug, 2015;42:261-272. [doi: 10.1016/j.humov.2015.06.002] [PMID: 26112404]
57. Aadland E, Ylvisåker E. Reliability of the Actigraph GT3X+ accelerometer in adults under free-living conditions. PLoS One. Aug 14, 2015;10(8):e0134606 [doi: 10.1371/journal.pone.0134606] [PMID: 26274586]
58. Roure C. Clarification du construit de l'intérêt en situation en éducation physique. STAPS. 2020;130(4):61-77. [doi: 10.3917/sta.130.0061]
59. Albaret JM, Aubert E. Étalonnage 15-19 ans du test de rotation mentale de Vandenberg. Evol. Psychom. Jan 1, 1996;8(34):205-215. https://www.researchgate.net/publication/240795056_Test_de_rotation_mentale_de_Vandenberg_etalonnage_15-19_ans [access July 10, 2025]
60. Vandenberg SG, Kuse AR. Mental rotation, a group test of three-dimensional spatial visualization. Percept Mot Skills. Dec, 1978;47(2):599-604. [doi: 10.2466/pms.1978.47.2.599] [PMID: 724398]
61. Dallolio L, Ceciliani A, Sanna T, Garulli A, Leoni E. Proposal for an enhanced physical education program in the primary school: evaluation of feasibility and effectiveness in improving physical skills and fitness. J Phys Act Health. Oct, 2016;13(10):1025-1034. [doi: 10.1123/jpah.2015-0694] [PMID: 27172612]
62. Harre D. Principles of sports training: introduction to the theory and methods of training. 1st edition. Berlin: Sportverlag; 1982. ISBN:3328000526
63. Vandorpe B, Vandendriessche J, Lefevre J, et al. The körperkoordinations test für kinder: reference values and suitability for 6-12-year-old children in Flanders. Scand J Med Sci Sports. Jun, 2011;21(3):378-388. [doi: 10.1111/j.1600-0838.2009.01067.x] [PMID: 20136753]
64. Nosworthy N, Bugden S, Archibald L, Evans B, Ansari D. A two-minute paper-and-pencil test of symbolic and nonsymbolic numerical magnitude processing explains variability in primary school children's arithmetic competence. PLoS One. Jul 2, 2013;8(7):e67918. [doi: 10.1371/journal.pone.0067918] [PMID: 23844126]
65. Vogel SE, Haigh T, Sommerauer G, et al. Processing the order of symbolic numbers: a reliable and unique predictor of arithmetic fluency. J Numer Cogn. Dec 22, 2017;3(2):288-308. [doi: 10.5964/jnc.v3i2.55]
66. Barrett TJ. Computations using analysis of covariance. WIREs Comp Stats. May-Jun, 2011;3(3):260-268. [doi: https://doi.org/10.1002/wics.165]
67. Conover WJ, Iman RL. Analysis of covariance using the rank transformation. Biometrics. Sep, 1982;38(3):715-724. [PMID: 7171697]
68. Huber SK, Held JPO, de Bruin ED, Knols RH. Personalized motor-cognitive exergame training in chronic stroke patients – A feasibility study. Front Aging Neurosci. Oct 20, 2021;13:730801. [doi: 10.3389/fnagi.2021.730801] [PMID: 34744688]
69. Wright R, Thompson WL, Ganis G, Newcombe NS, Kosslyn SM. Training generalized spatial skills. Psychon Bull Rev. Aug, 2008;15(4):763-771. [doi: 10.3758/PBR.15.4.763] [PMID: 18792502]
70. Di Cagno A, Battaglia C, Giombini A, et al. Time of day – Effects on motor coordination and reactive strength in elite athletes and untrained adolescents. J Sports Sci Med. Mar 1, 2013;12(1):182-189. [PMID: 24149743]
71. Arsalidou M, Pawliw-Levac M, Sadeghi M, Pascual-Leone J. Brain areas associated with numbers and calculations in children: meta-analyses of fMRI studies. Dev Cogn Neurosci.

Apr, 2018;30:239-250. [doi: 10.1016/j.dcn.2017.08.002] [PMID: 28844728]
72. Metcalfe AWS, Campbell JID. Adults' strategies for simple addition and multiplication: verbal self-reports and the operand recognition paradigm. J Exp Psychol Learn Mem Cogn. May, 2011;37(3):661-672. [doi: doi.org/10.1037/a0022218] [PMID: 21261421]
73. Yang X, Yu X. The relationship between mental rotation and arithmetic: do number line estimation, working memory, or place-value concept matter? Br J Educ Psychol. Sep, 2021;91(3):793-810. [doi: 10.1111/bjep.12403] [PMID: 33368175]
74. Li M, Liu D, Li M, Dong W, Huang Y, Chen Q. Addition and subtraction but not multiplication and division cause shifts of spatial attention. Front Hum Neurosci. May 3, 2018;12:183. [doi: 10.3389/fnhum.2018.00183] [PMID: 29773985]

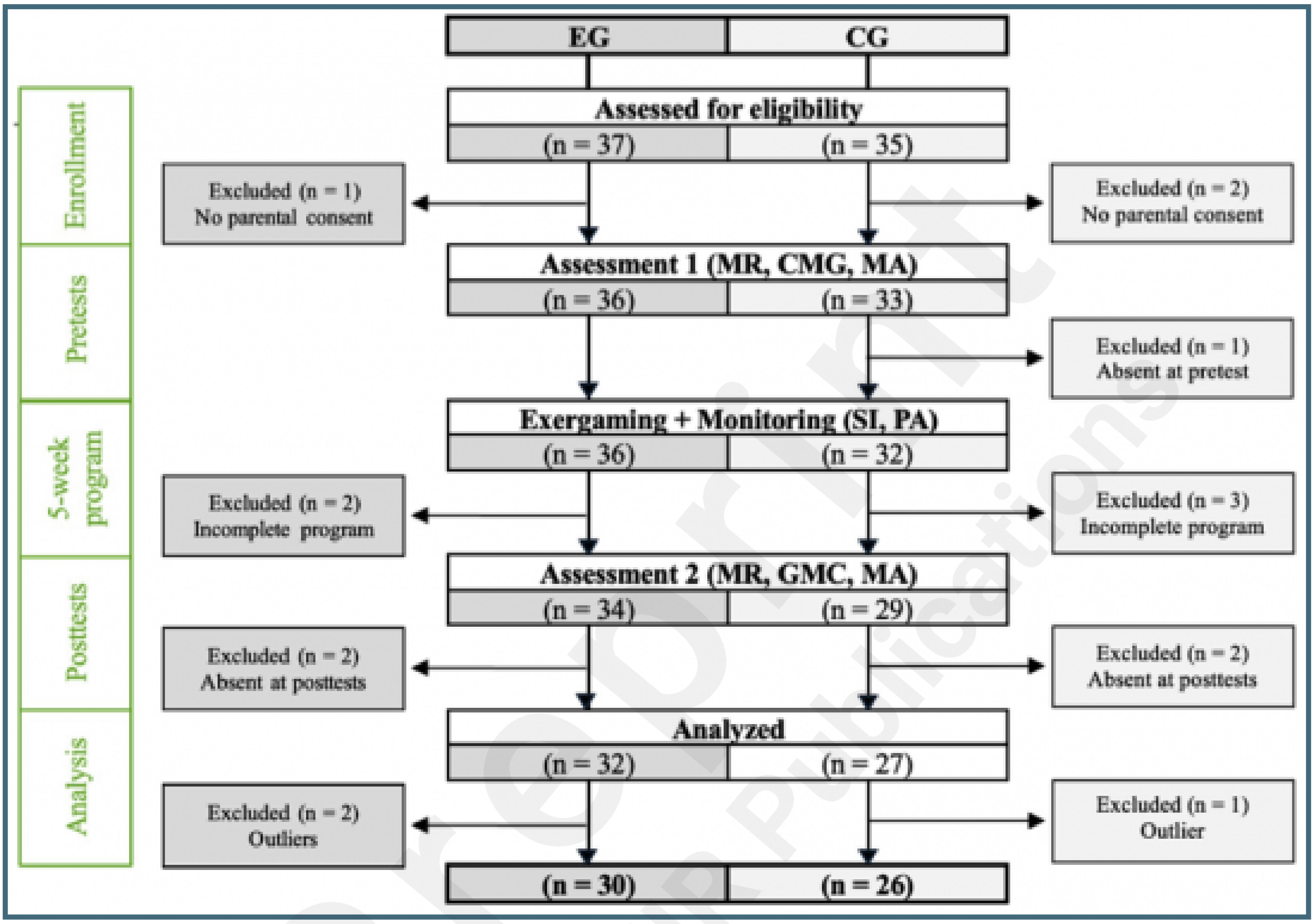
Abbreviations

CG: control group
DEx: dance-based exergaming
EG: experimental group
PE: physical education
MVPA: moderate-to-vigorous physical activity
TEx: exergaming based on precision ball-throwing

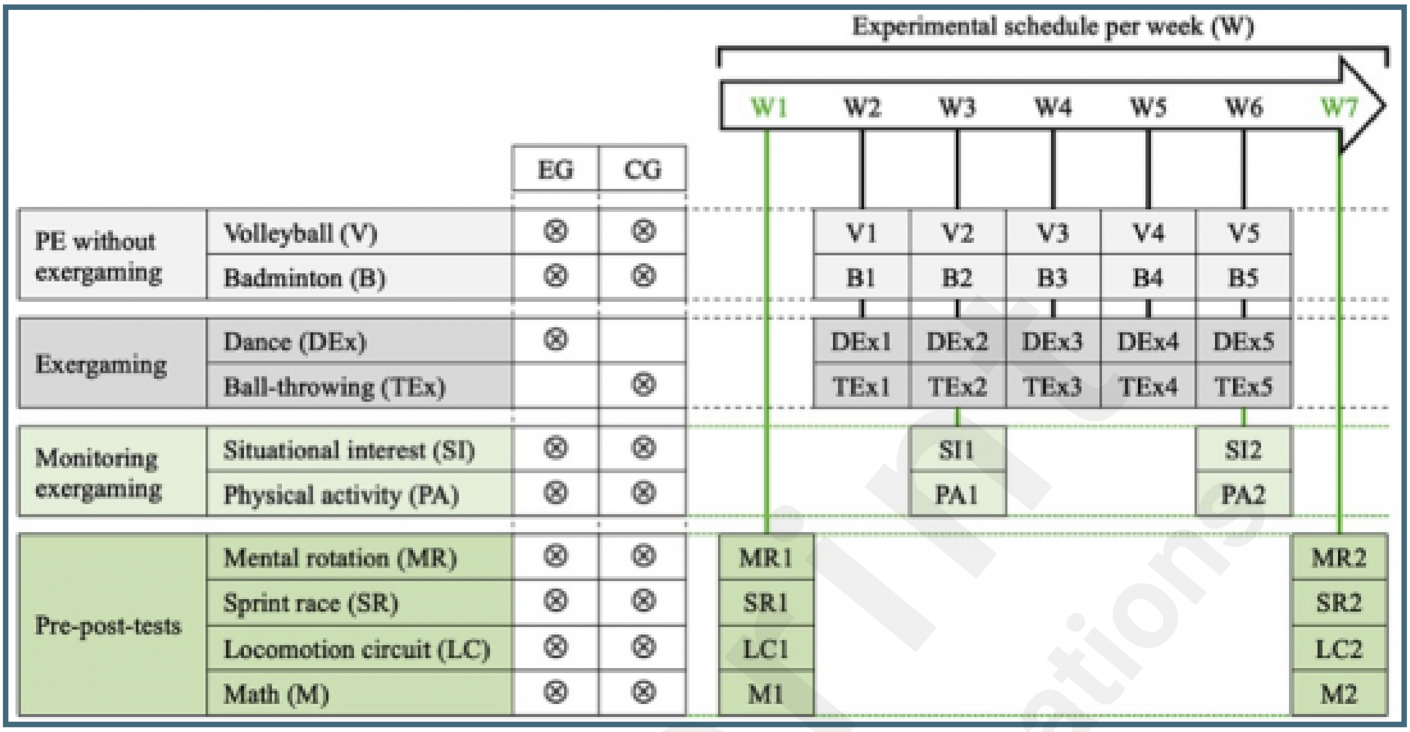
Supplementary Files

Figures

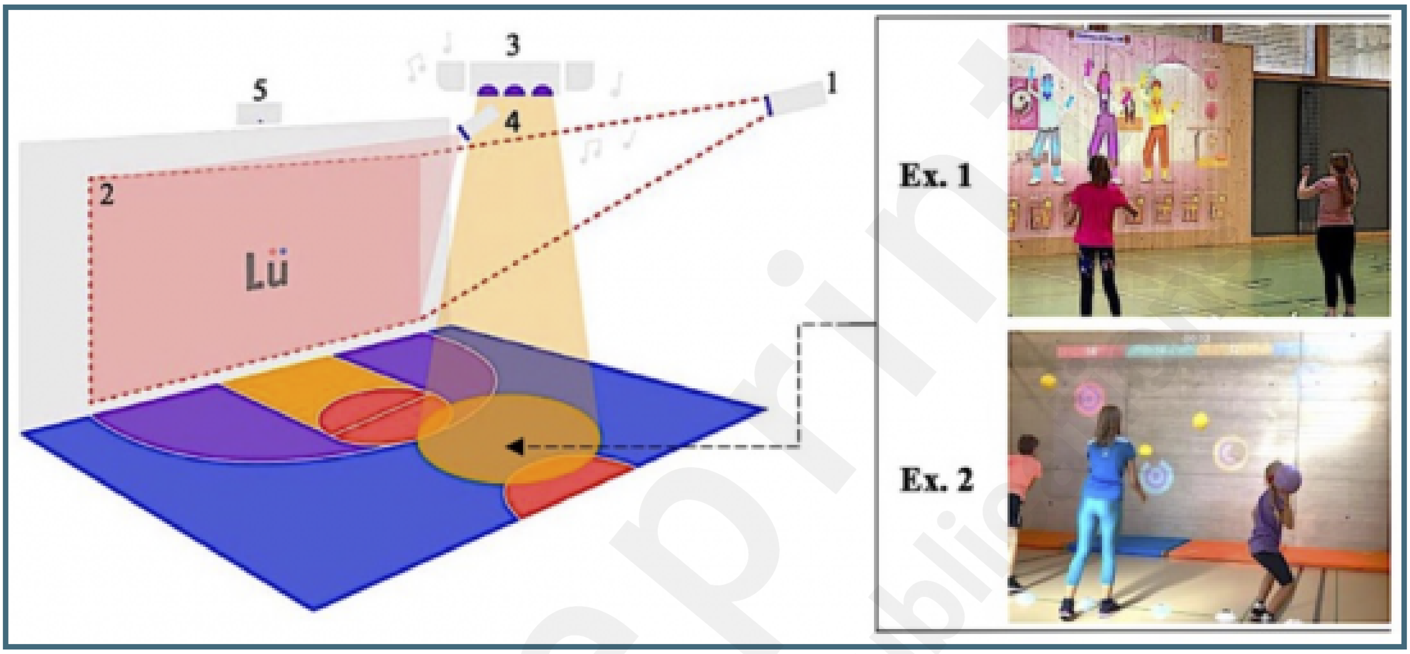
Study flow chart. In Figure 1, Assessments 1 and 2 targeted mental rotation (MR), general motor coordination (GMC), and math achievement (MA). During exergaming sessions, situational interest (SI), and intensity levels of physical activity (PA) were also monitored.



Experimental design.



Overview of the Lü Üno system. Figure 3. shows a drawing of the Lü® Üno system, i.e., a single wall configuration mounted to the ceil of a gymnasium, with: 1. High-definition laser projection (5200 lumens), 2. Image (6m x 3m), 3. Multicolored LED lighting system with moving lights and sound system with dual speakers (2400 Watts), 4. Movement detection camera allowing interaction with the projected images, and 5. Internal computer with a webcam. Ex. 1 and Ex. 2 show, as examples, photographs of exergames practice during the experiment, with: Grööve (Ex. 1), during which the experimental subjects reproduced dance movements shown by avatars, and Target (Ex. 2), during which the control subjects threw balls to hit targets.
.



Using the exergame Grööve. The application Grööve allows to practice part of a dance, as well as the entire dance, reproducing movements demonstrated by avatars and indicated by drawings. The screenshot shows an example of movements included in the dance learned during the experiment, that were visualizable on a screen. The available options to adapt the practice difficulty to the subjects are also shown; these allowed to control the movements' speed (x1.00, x0.75, or x0.50) and/or the sound played (metronome only, metronome and music, or music only). The application also allows to pause the video ("Pause" button) and to save the progress of the subjects learning a dance ("Mastered" button).

Multimedia Appendixes

Dance-based exergaming sequence.
URL: http://asset.jmir.pub/assets/0a284a94560d6d8cf566bd2efb4380f5.pdf

Exergaming sequence based on precision ball-throwing (TEx).
URL: http://asset.jmir.pub/assets/edbc5f3dd0dc1aeed16879409609e20b.pdf

Situational interest monitoring.
URL: http://asset.jmir.pub/assets/64b30dbf0ff28454efc517693017272c.pdf

Pretests and posttests.
URL: http://asset.jmir.pub/assets/f6cc679c7e39b0cb193ba0c99223fea0.pdf

CONSORT-EHEALTH (V 1.6.1) - Submission/Publication Form.
URL: http://asset.jmir.pub/assets/da748b80768787fa5923356d37e7cd29.pdf