Situational Interest Impacts College Students' Physical Activity in a Design-Based Bike Exergame

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University Bourgogne Franche-Comté
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Cédric Roure
University of Teacher Education, State of Vaud (HEP-VD) - Lausanne
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Original article

Situational interest impacts college students' physical activity in a design-based bike exergame

Denis Pasco[a],*, Cédric Roure[b]

[a] School of Education, University of Bourgogne Franche-Comté, Besançon 25000, France

[b] Teaching and Research Unit in Physical Education and Sport, University of Teacher Education, Lausanne, State of Vaud 1014, Switzerland

Running title: Design-based exergame physical activity

*Corresponding author.

Email address: denis.pasco@univ-fcomte.fr (D. Pasco)

Highlights

• Playing a design-based bike exergame increases players' physical activity metrics (i.e., heart rate, oxygen consumption, and cadence).

• Psychological state (i.e., situational interest) impacts physiological metrics in a design-based bike exergame.

• An approach using design-based exergames or active videogames is a powerful strategy for promoting physical activity levels that yield positive health-related outcomes.

Abstract

Background: Active videogames or exergames have been used as an innovative way to promote physical activity among various populations. A player's interest in active videogames is associated with the fun and entertaining nature of the games and may trigger situational interest, thus increasing engagement. The goal of this study was to examine the impact of situational interest dimensions on college students' physical activity when playing the design-based bike exergame Greedy Rabbit (Vescape®, Berlin, Germany).

Methods: Sixty undergraduate students (age: mean = 20.8 years, SD = 1.3 years, 18–25 years old; 51.7% males) were recruited from the kinesiology department of a university located in the southern region of Belgium. The participants were assigned to an experimental group ($n = 41$) or a control group ($n = 19$) based on an incremental cycling test. Students in the experimental group engaged in 1 session of Greedy Rabbit while students in the control group engaged in 1 session of a placebo version of Greedy Rabbit. The length of the sessions ranged from 24 min to 31 min.

Results: Results for the control group indicated that the players' physical activity metrics (cadence: $F(19,360) = 1.43$, $p = 0.11$; heart rate: $F(19,360) = 1.16$, $p = 0.29$; oxygen consumption, $F(19,360) = 0.83$, $p = 0.67$) were stable during the exergame. Results for the experimental group demonstrated the effects of time on the players' physical activity metrics and revealed significant associations between the change in the players' situational interest dimensions and physical activity metrics (cadence: $F(19,800) = 26.30$, $p < 0.01$; heart rate: $F(19,800) = 19.77$, $p < 0.01$; oxygen consumption, $F(19,800) = 10.04$, $p < 0.01$).

Conclusion: An approach using a design-based exergame may be a relevant strategy for promoting levels of physical activity that yield positive health-related outcomes among college students.

Keywords: Active videogame; College students; Exergame; Physical activity; Situational interest

1. Introduction

In a recent study, Guthold et al.[1] described the current prevalence and trends of insufficient physical activity (PA) among a population of school-going adolescents aged 11–17 years. Using a pooled analysis of 298 population-based surveys from 146 countries with 1.6 million participants, their study found that 81% of this population was insufficiently physically active. These poor PA behaviors are likely to continue into college because college students often make lifestyle choices (e.g., PA behaviors, dietary choices) autonomously for the first time.[2] PA guidelines for aerobic exercise recommend that adults participate in (1) ≥150 min/week of moderate-intensity PA, (2) ≥75 min/week of vigorous-intensity PA, or (3) an equivalent combination of the two.[3] However, despite the well-known benefits of PA,[4] 80% of college students fail to meet these PA guidelines.[5]

Over the last decade, active videogames or exergames, which are defined as "video games that are also a form of exercise", have been used as an innovative way to promote PA among various populations. The use of these exergames is based on people's interest in videogames and on their fun and entertaining nature.[6–13] According to Sun,[14] exergames can induce a high level of situational interest (SI), which is defined as the appealing effect of an activity on individuals. SI is conceptualized as a multidimensional construct encompassing 5 dimensions: novelty, challenge, attention demand, exploration intention, and instant enjoyment.[15–17] Within the exergaming literature, researchers have investigated the link between SI and moderate-to-vigorous PA (MVPA).[18,19] Huang and Gao[18] found that novelty was a significant predictor of junior high students' MVPA when the students played Dance Dance Revolution (DDR), while Sun and Gao[19] found a significant correlation between exploration intention and elementary school students' mean heart rate when the students played a game involving movements.

However, as Baranowski, Lyons, and Thompson[20] point out: "Although active videogames have increased PA under certain circumstances, simply providing participants with active videogames do not increase PA". Also, despite the benefits of traditional exergames, players might not spend most of their time in PA levels compatible with positive health outcomes (i.e., MVPA). Recently, a strategy in game design called "design-based exergame approach" has emerged as a way to address this issue.[21,22] Within the design-based exergame approach, game designers and researchers collaborate to design exergames that promote the players' health-related PA outcomes. Using this approach with a mobile application-based bike exergame

platform called Greedy Rabbit (Vescape®, Berlin, Germany), Pasco et al.[21] found that players spent 90% of their time in MVPA levels when playing the bike exergame. They also found that the experimental group playing Greedy Rabbit reported significantly higher scores on all SI dimensions compared to a control group engaged in a free cycling. Using an upgraded version of Greedy Rabbit, Roure et al.[22] found that an experimental group of players demonstrated significantly higher scores for PA metrics (i.e., heart rate, oxygen consumption, and cadence) and for 2 SI dimensions (i.e., instant enjoyment and attention demand) compared to a control group playing a placebo version of Greedy Rabbit (i.e., without the game elements). Even though previous studies have yeilded interesting results concerning PA metrics and SI when players are involved in a design-based exergame, we still lack information about the relationships between the entertainment features of such games (i.e., the SI dimensions) and the PA generated (i.e., the PA metrics). Therefore, in this study, we investigated the extent to which the players' perception of SI dimensions related to the impact of the game design on their PA metrics (including oxygen consumption, heart rate, and cadence). Identifying specific SI dimensions that may impact the players' PA can significantly improve the design process of active videogames in order to target PA levels that make them compatible with positive health-related outcomes. Thus, the purpose of this study was to examine the impact of SI dimensions on the PA level of college students when they played the design-based bike exergame Greedy Rabbit.

2. Material and methods

We collaborated with Vescape® (https://www.vescape.com), the company that designed the mobile application-based exergame platform called Greedy Rabbit. This platform can be installed on an iPad that is paired with an exercise bike (Skandika cardiobike Ulisses SF-1610; Skandika, Essen, Germany) via a Bluetooth protocol.

2.1. Participants

An experimental design was used to examine the relationship between the players' SI dimensions and their PA metrics (i.e., oxygen consumption, heart rate, and cadence) when playing Greedy Rabbit. The sample size calculation using G*Power 3.1 (https://www.psychologie.hhu.de/en/research-teams/cognitive-and-industrial-psychology/gpower.html) indicated that 60 participants would be sufficient for 80% power (α = 0.05, effect size = 0.30) to test the primary outcome (i.e., SI). Thus, the participants who volunteered to participate comprised 60 undergraduate students (age: mean = 20.8 years, SD =

1.3 years, 18–25 years old; 51.7 % males) recruited from the kinesiology department of a university located in the southern region of Belgium. The inclusion criteria for participation required that participants be under 30 years of age and that there be a balance between males and females. The exclusion criteria eliminated those who had a chronic disease or condition that would limit their PA. Permission to conduct the study was granted by the Ethics Committee of the Catholic University of Louvain-la-Neuve (approval number: B403201630077). Participants were informed about the scope of the study, with written informed consent gathered prior to data collection. They were not compensated for their participation. Human subject protections provided during the experimentation included constant medical supervision and insurance subscription (number: 45.327.621).

2.2. Procedures

Each participant completed 2 visits to the laboratory within 3 weeks. During the first visit, demographic information, such as age, sex, and height and weight (body mass index (BMI)), was collected for all participants. Researchers used this information to initialize and calibrate the metabolic cart for the oxygen consumption measure. Then, each participant completed an incremental cycling test on a bicycle ergometer (Corival® Lode, Lode B.V., Groningen, The Netherlands) to calculate maximal oxygen consumption (VO_{2max}), maximal aerobic power (MAP), and maximal heart rate (HR_{max}). This test involved cycling at different stages with increasing levels of difficulty based on power output. The initial level was set at 70Watt (W), which increased by 40W every 3 min. Based on the participants' VO_{2max}, MAP, and HR_{max} obtained from this test, the researchers allocated the participants into 2 groups (experimental group: $n = 41$; control group: $n = 19$), with similar distributions between both groups in relation to these 3 physiological variables. More precisely, clusters were identified so that participants would have closed mean scores on these 3 variables. In each cluster, the researchers separated the participants at random by allocating them in each group. This procedure was used to ensure that there was homogeneity between both groups in terms of the participants' VO_{2max}, MAP, and HR_{max} and allowed researchers to choose the intensity of practice during the exergame, in percentages of MAP, for each participant.

During the second visit, participants played either the experimental version or the placebo version of Greedy Rabbit. Researchers introduced and demonstrated how to play the exergame during a 10-min warm-up. This warm-up was standardized for all participants and consisted of

cycling at 50% of a player's MAP. During the first 8 min of the 10-min warm-up, the researchers introduced the exergame and its basic principles (i.e., its elements, including the rabbit, the hedgehogs, and the number of stages). Then, during the last 2 min of the warm-up, the players tested the first 2 stages of Greedy Rabbit. After this warm-up, players in the experimental group engaged in 1 session of Greedy Rabbit, consisting of 32 stages divided in 4 sets of 8 stages. These 4 sets were designed by the Vescape® company with the idea of progressively increasing the difficulty of the game and to mirror the principles of general video games, most of which are divided into progressive levels. The 32 stages were played without pausing between the 4 sets. Each stage was designed as a Pac-Man-like labyrinth, with a rabbit controlled by the participant and 1 or more hedgehogs controlled by the computer. Flowers were collected and lead to the goal, which was represented by a carrot. Players had to cycle to control the speed of the rabbit, which was pursued by 1 or more hedgehogs. The speed of the rabbit was dependent on the cycling frequency, whereas the speed of the hedgehogs was set by the computer and varied across the stages. In the control group, players engaged in 1 session of a placebo version of Greedy Rabbit, which consisted of the same 32 stages. This placebo version also was designed as a Pac-Man-like labyrinth, with a rabbit controlled by the participant, but the most significant game elements were removed (i.e., the hedgehogs, the flowers, and the carrot representing the goal). Without these elements, the only goal for the players was to choose their own cycling frequency that would allow the rabbit to complete the 32 stages.

For both groups, the intensity of the exercise was constant during the exergame. There were 3 choices for level of difficulty: easy (130W), medium (180W), and hard (230W). This choice was based on a player's MAP and was determined after the incremental cycling test to ensure that the intensity ranged between 65% and 85% of a player's individual MAP as recommended by the American College of Sport Medicine.[23] Time to complete the 32 stages ranged from 24 min to 31 min, depending on a player's cycling frequency. Five min after the experiment, players responded to the French 15-item SI scale.[24] This rest period was necessary to remove the participant's equipment (i.e., heart rate monitor and breath mask) and to allow participants to have a minimum recovery period before concentrating on their responses to the questionnaire. Researchers administered the questionnaire and collected it directly after it was completed.

2.3. Measures

SI—the French 15-item SI Scale was used to measure the players' SI during the exergame.[24] Roure et al.[24] established the construct validity of the French SI Scale using exploratory and confirmatory factor analyses (goodness of fit index = 0.93, normed fit index = 0.93, comparative fit index = 0.96, root mean squared error of approximation = 0.06).

PA metrics—participants in both groups wore a heart rate monitor to record their heart rate (beat/min) via a telemetry monitor (HxM BT Heart Rate Monitor, Zephyr^{TM} Performance Systems, Ergocard, Medisoft, Sorinnes, Belgium). They were asked to breathe through a mask that recorded their VO_2 (L/min) via indirect calorimetry using a calibrated metabolic cart (Ergocard, Medisoft, Annapolis, Maryland, USA). Prior to each exergame session, the metabolic cart was calibrated with room air and standard gases of known volume and concentration for the oxygen and carbon dioxide analyzers. In addition, cadence (revolutions per minute (rpm)) was continuously recorded every second by Vescape® software.

2.4. Data analyses

The players' responses to the questionnaire were aggregated respectively to the 5 dimensions of SI (i.e., novelty, challenge, attention demand, exploration intention, and instant enjoyment). Since the length of the exergame sessions was different according to group membership and players, the PA metrics were coded and standardized in 20 intervals, with each interval representing 5% of the total exergame length. This procedure was also used to synchronize the 3 PA metrics (oxygen consumption, heart rate, and cadence). The statistical analyses were then performed in the following steps. Preliminary analyses were first conducted on study variables to examine normality, multicollinearity, and internal reliability of the subscales. Then, in order to confirm group homogeneity prior to the experiment, a multivariate analysis of variance (MANOVA) was performed to check if the students' PA measures (BMI, VO_{2max}, HR_{max}, and MAP) were the same in both groups. Pillai's F statistic was used to determine the statistical significance of the multivariate model because it controls for type I error rate with unequal sample sizes. Finally, for each group, the changes in the PA metrics and the association of SI dimensions with the changes in the PA metrics were analyzed using a linear mixed model, with time as the repeated factor using a repeated diagonal covariance structure. The

model included the mean value of each SI dimension as a covariate and the changes in PA metrics as the dependent variables. Fixed effects were group membership, SI dimensions, and their interactions. The random intercept for subject was included in all mixed models in order to fit subject-specific models. SPSS (Version 23.0; IBM Corp., Armork, NY, USA) was used for all statistical analyses.

3. Results

3.1. Preliminary analyses

Analysis of the skewness values (–0.34 to 0.71) and kurtosis values (–0.78 to –0.14) revealed that the data were normally distributed, except for the novelty component (because all participants found the exergame new). No problem of multicollinearity between variables was found. Internal consistencies of the SI scale were good, with Cronbach's α of 0.88 for novelty, 0.79 for challenge, 0.84 for attention demand, 0.81 for exploration intention, and 0.82 for instant enjoyment. The results from MANOVA revealed that the control group and the experimental group did not differ significantly in BMI, VO_{2max}, HR_{max}, or MAP before the exergame intervention (Pillaï Trace = 0.02; $F(4,55) = 0.27$, $p = 0.90$; $\eta^2 = 0.02$).

3.2. Change in the players' PA metrics in relation to SI

The results from mixed models for the control group revealed no effects of time on the players' PA metrics: cadence, $F(19,360) = 1.43$, $p = 0.11$; heart rate, $F(19,360) = 1.16$, $p = 0.29$; oxygen consumption, $F(19,360) = 0.83$, $p = 0.67$. The players' PA metrics were stable during the exergame. On the contrary, mixed models for the experimental group did demonstrate effects of time on the players' PA metrics: cadence, $F(19,800) = 26.30$, $p < 0.01$; heart rate, $F(19,800) = 19.77$, $p < 0.01$; and oxygen consumption, $F(19,800) = 10.04$, $p < 0.01$. More precisely, the results from linear regression showed that the cadence increased with time: cadence = 88.35 + 0.93 × interval, (23.5% of its variance explained). Similarly, heart rate increased with time: heart rate = 141.00 + 1.63 × interval (24.6% of variance explained). Because the players' HR_{max} was known from the incremental cycling test, the results can be expressed as $\%HR_{max}$ = 75.22 + 0.86 × interval (27.8% of the total variance explained). Finally, oxygen consumption also increased with time: oxygen consumption = 1.89 + 0.03 × interval (13.1% of variance explained) and $\%VO_{2max}$ = 62.80 + 0.96 × interval (13.3% of variance explained). These results show that the exergame increased the players' PA metrics as they progressed through the 32 stages.

Additionally, the results from further mixed models revealed significant associations for the experimental group between changes in the players' PA metrics and SI dimensions. More precisely, the increase of the cadence was associated significantly with instant enjoyment, $F(1,603.63) = 7.86$, $p < 0.01$; exploration intention, $F(1,607.67) = 7.26$, $p < 0.01$; and attention demand, $F(1,603.06) = 4.53$, $p < 0.05$. The players' cadence increased in relation to higher scores for instant enjoyment (cadence = $91.57 + 0.59 \times$ instant enjoyment score) and attention demand (cadence = $97.66 + 0.20 \times$ attention demand score), whereas it decreased in relation to higher scores for exploration intention (cadence = $101.32 - 0.28 \times$ exploration intention score). Fig. 1 represents the association between these 3 SI dimensions and the changes in the players' cadence.

Similarly, the increase in the players' $\%HR_{max}$ was associated significantly with challenge, $F(1,749.96) = 86.89$, $p < 0.01$; exploration intention, $F(1,756.67) = 10.12$, $p < 0.01$; and instant enjoyment, $F(1,757.39) = 4.32$, $p < 0.05$. The players' $\%HR_{max}$ increased in relation to higher scores for challenge ($\%HR_{max} = 77.1 + 1.24 \times$ challenge score) and decreased in relation to higher scores for exploration intention ($\%HR_{max} = 88.35 - 0.32 \times$ exploration intention score) and instant enjoyment ($\%HR_{max} = 90.97 - 0.43 \times$ instant enjoyment score). Fig. 2 represents the association between these 3 SI dimensions and the changes in the players' $\%HR_{max}$.

Finally, the increase in the players' $\%VO_{2max}$ was associated significantly with exploration intention ($F(1,776.91) = 13.85$, $p < 0.01$); challenge ($F(1,779.32) = 9.35$, $p < 0.01$); and attention demand ($F(1,778.94) = 4.73$, $p < 0.05$). The players' $\% VO_{2max}$ increased in relation to higher scores for challenge ($\%VO_{2max} = 68.29 + 0.72 \times$ challenge score) and attention demand ($\%VO_{2max} = 69.93 + 0.35 \times$ attention demand score) and decreased in relation to higher scores for exploration intention ($\%VO_{2max} = 79.35 - 0.64 \times$ exploration intention score). Fig. 3 represents the association between these 3 SI dimensions and the changes in the players' $\%VO_{2max}$.

4. Discussion

The present study investigated the impact of SI dimensions on college students' PA when playing a design-based bike exergame. Participants in the experimental group demonstrated effects of time on the players' PA metrics, including cadence, heart rate, and oxygen consumption, as they progressed through the 32 stages of the exergame. Moreover, college students' SI dimensions impacted the 3 PA metrics for the experimental group. Cadence was impacted by instant

enjoyment, exploration intention, and attention demand; heart rate was impacted by challenge, exploration intention, and instant enjoyment; and oxygen consumption was impacted by exploration intention, challenge, and attention demand. The impact of these 4 SI dimensions on the players' PA metrics are discussed in relation to the SI model of Roure and Pasco[25] and in relation to the literature on game design.

Results from this study reveal that instant enjoyment and challenge play an important role in influencing the players' PA metrics because they are involved in changes positively related to cadence (instant enjoyment), heart rate (instant enjoyment and challenge), and oxygen consumption (challenge). However, the results can be understood as ambivalent at first sight, especially for instant enjoyment, since higher scores are needed to improve the players' cadence while lower scores are preferable to improve the players' heart rate. This ambivalent result can be interpreted as the need to find an optimal level of instant enjoyment. In addition to this optimal level, it should be beneficial to the players' PA to set adequate levels of challenge. The combination of instant enjoyment and challenge seems well founded according to a previous study by Roure and Pasco,[25] who investigated the relationships among the SI dimensions in PA settings.[25] In their study, they found that challenge, defined as the level of difficulty relative to one's ability, was negatively correlated to instant enjoyment, defined as the characteristics that lead the learner to an instant positive feeling of being satisfied. In this sense, the results of our study further confirm the need to find a balance between the promotion of these 2 dimensions in order to improve the players' PA.[26–30] Based on the results from our study, we recommend setting the challenge perceived by players between 7 and 11, and the perception of their instant enjoyment between 9 and 12, in order to positively impact all 3 PA metrics at the same time. Game designers usually mobilize progressive challenges and rewards (which can be related to instant enjoyment) as key elements in the game design.[31–33] Results from our study indicate that, when designing exergames, games designers should be careful to balance challenge and instant enjoyment because inadequate levels of challenge may affect the rewards for the players (i.e., instant enjoyment) and their PA metrics (cadence, heart rate, and oxygen consumption). Based on our results, balancing the levels of challenge and instant enjoyment in order to promote the players' PA within the exergame might be accomplished by (1) having each player set an adequate level of challenge through 3 modes of progressive challenge (e.g., recreational, sport, and expert) prior to playing Greedy Rabbit or (2) including an initial training module in the

exergame in order to evaluate each player's PA level to ensure adequate levels of challenge throughout the 32 stages.

Results from our study also reveal that exploration intention and attention demand play a crucial role in enhancing the players' PA metrics because these SI components are involved in cadence (exploration intention and attention demand), heart rate (exploration intention), and oxygen consumption (exploration attention and attention demand). The results from our study indicate that while attention demand can be set at the highest possible levels, exploration intention should be under 14 for cadence, under 12 for heart rate, and under 10 for oxygen consumption because higher scores for exploration intention negatively impact the players' PA metrics (negative slopes of –0.28 for cadence, –0.32 for heart rate, and –0.64 for oxygen consumption). Similar to the recommendation made for instant enjoyment and challenge, a balance between players' attention demand and exploration intention should be targeted, considering the relationships between these SI dimensions in PA settings.[25] Indeed, Roure and Pasco[25] found that exploration intention, defined as the learning aspects that drive the learner to explore and discover, was positively correlated with attention demand, defined as the concentrated cognition and mental energy required in learning an activity.[29] Accordingly, within the game design, these SI dimensions can be related to the choices given to the players in a game and to the players' concentration.[34–37] Giving choices to an individual can trigger a willingness to explore and discover the game's environment and is one of the key factors in sustaining intrinsic motivation (i.e., motivation to engage in a task focusing on developing and learning new skills and motivation to demonstrate mastery of the task).[38–40] Transposing exploration intention and attention demand into the players' choices and concentration may lead game designers to (1) increase opportunities for players to focus their attention on relevant elements of the exergame (e.g., in Greedy Rabbit, by increasing the number of hedgehogs or assigning different speeds to multiple hedgehogs) or (2) limit the players' alternatives by using repeated simple choices (e.g., in Greedy Rabbit, by offering players only 2 or 3 pathways within some stages).

Our study is one of the first attempts to provide evidence about the impact of a psychological state (i.e., the players' SI) on physiological metrics (i.e., the players' cadence, heart rate, and oxygen consumption) in a design-based bike exergame, thus fostering new knowledge that can be applied to game design for exercise. However, there are some limitations to our study that must be addressed. First, our study was completed in 1 geographic location using a sample of

students from a university's kinesiology department, thus limiting the generalizability of our findings. Therefore, future researchers may want to implement Greedy Rabbit among a more diverse sample of students from multiple universities. Second, our results were based on 32 stages of Greedy Rabbit, which represented a relatively short exposure to the exergame. Future studies that use a longitudinal design are needed to better understand the evolution of the impact of SI dimensions on the players' PA metrics. Third, the individual interest that the players had in a bike exergame was not measured in our study. Future studies should assess this variable in order to disentangle the effects of the interest of individuals and their SI on their PA metrics within exergame playing. Finally, the design-based exergame approach requires researchers to collaborate with game designers and engineers. This can be an issue because they do not necessarily share the same goals. Researchers should work with game designers to create and implement environments within traditional exergames that foster the players' PA. This may be a way to address this issue.

5. Conclusion

The results from this study provide empirical evidence related to the impact of a player's psychological state (i.e., SI dimensions) on the player's PA metrics in a design-based bike exergame. Our findings suggest that a design-based exergame approach may be a relevant strategy for promoting PA levels compatible with positive health-related outcomes among college students. Given the result of our study, and the fact that millions of students are enrolled in college around the world, college administrators may want to consider implementing the Greedy Rabbit exergame in their student recreation centers as a complementary and effective alternative for students who want to engage in PA. The application is easy to deploy in recreation centers equipped with exercise bikes that have Bluetooth, and it is free to download on any tablet. Additionally, this study may help health professionals who want to promote PA participation and adherence among various populations using a design-based exergame strategy.

Authors' contributions

DP played a role in developing the idea, overseeing data collection, and writing the article; CD played a role in data collection, statistical analyses, and writing the article. Both authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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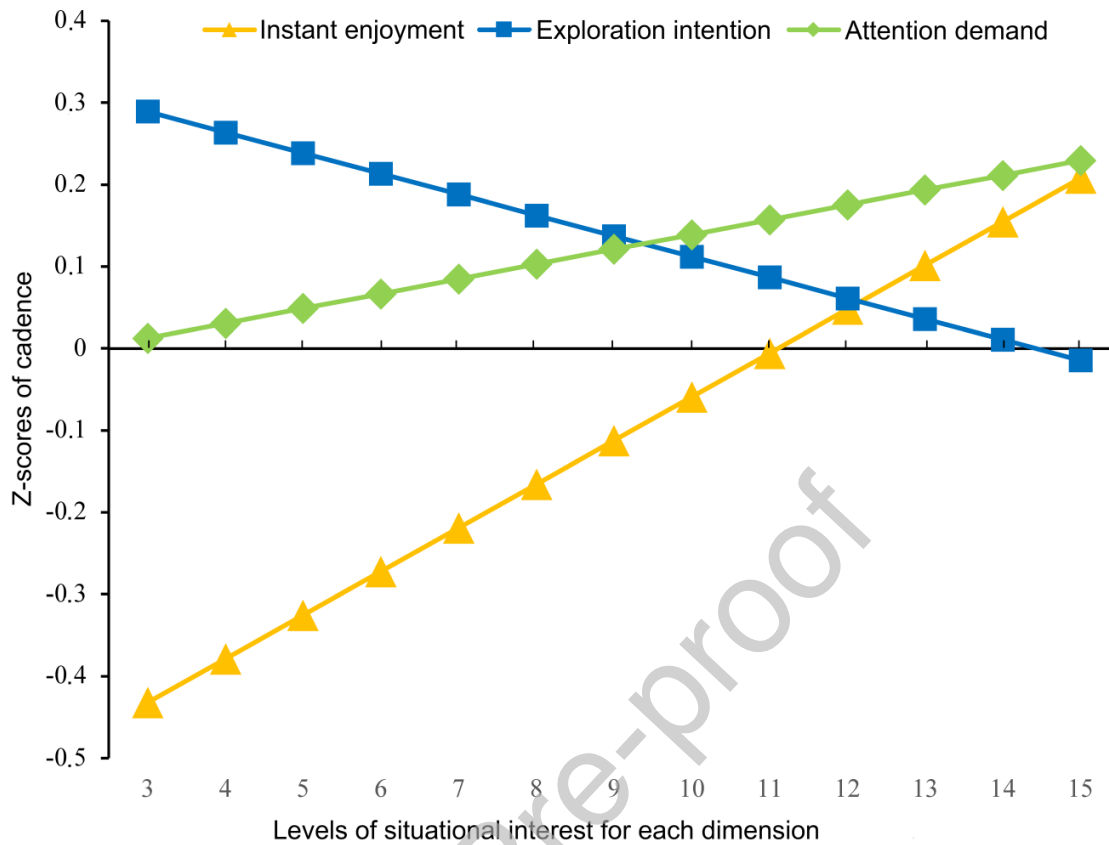
Fig. 1. Associations between students' situational interest and cadence for the experimental group. The y-axis represents the *Z*-scores, which give the relative position of the cadence average in the total sample for each situational interest dimension listed on the x-axis.
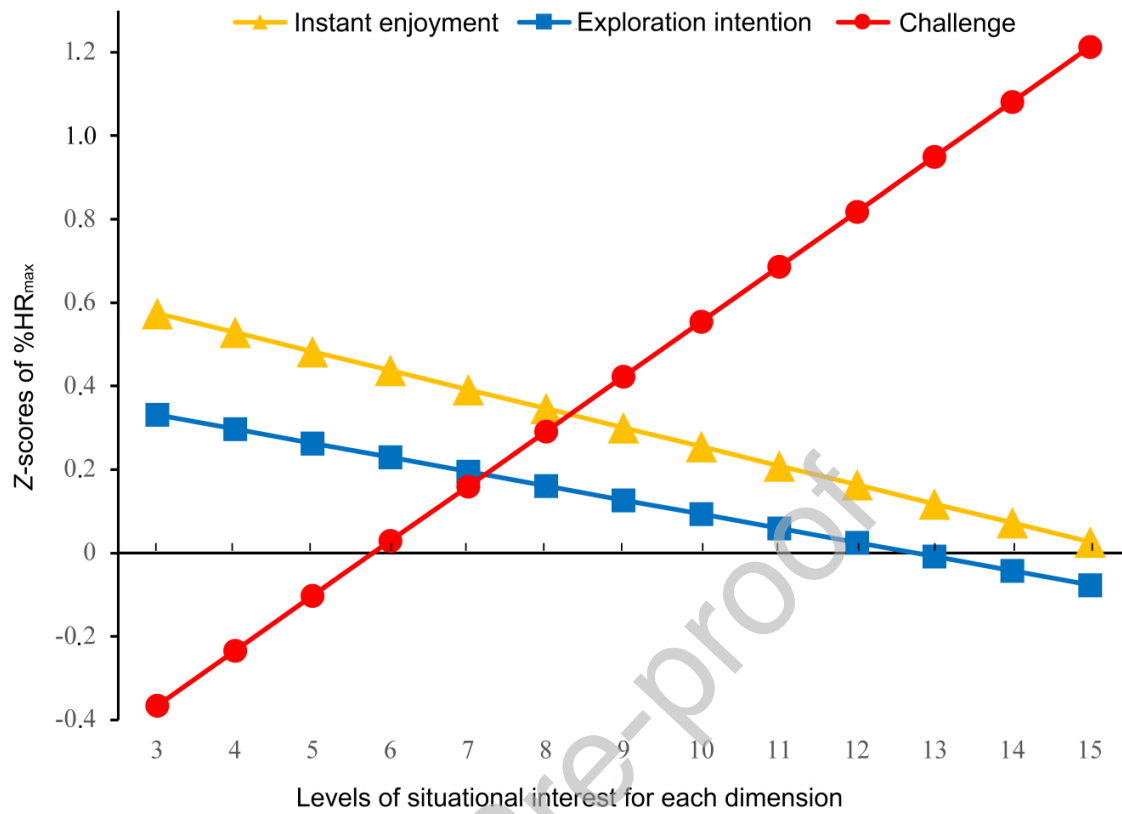
Fig. 2. Associations between students' situational interest and $\%HR_{max}$ for the experimental group. The y-axis represents the Z-scores, which give the relative position of the $\%HR_{max}$ average in the total sample for each situational interest dimension listed on the x-axis. $\%HR_{max}$ = maximal heart rate.
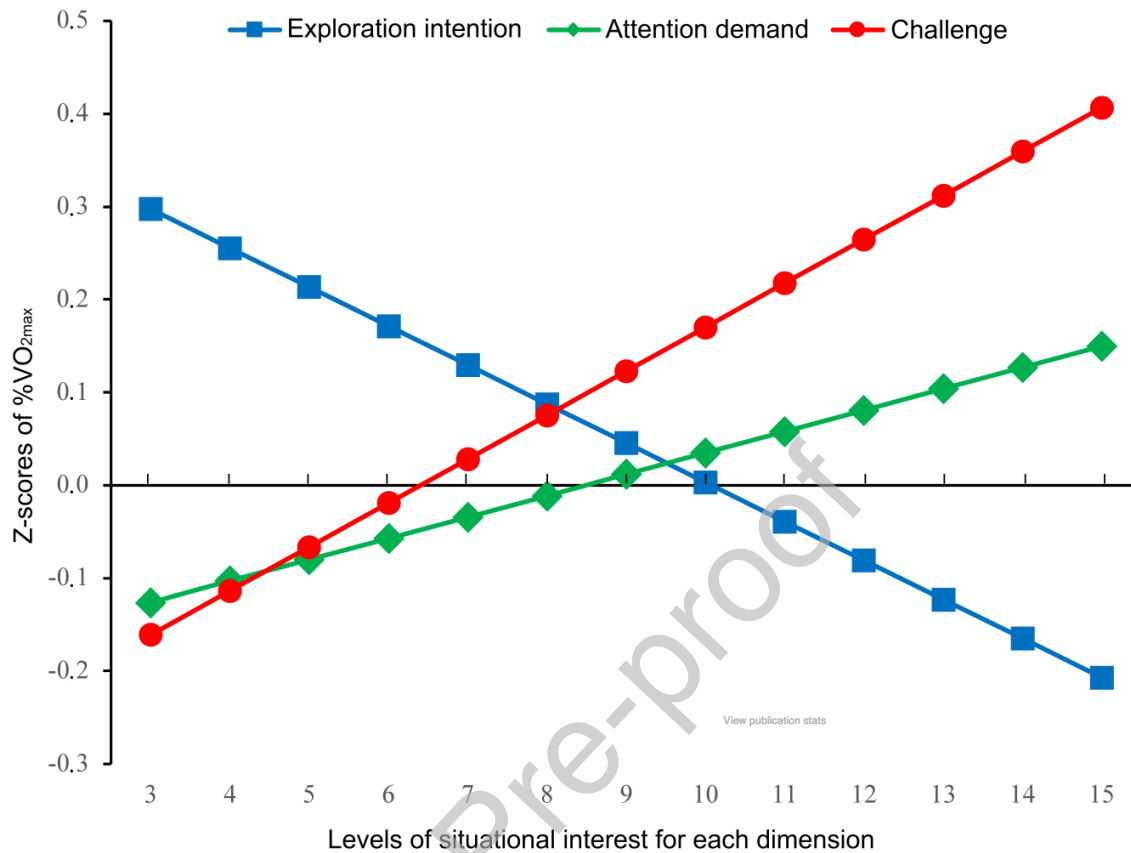
Fig. 3. Associations between students' situational interest and $\%VO_{2max}$ for the experimental group. The y-axis represents the Z-scores, which give the relative position of the $\%VO_{2max}$ average in the total sample for each situational interest dimension listed on the X-axis. $\%VO_{2max}$ = maximal oxygen consumption.