Exercise Physiology

Cardiovascular physiology and autonomic heart control principles: the use of a station rotation strategy to recall basic cardiovascular knowledge among exercise science students

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Abstract - Aim: Cardiovascular physiology learned by exercise science students is often quickly forgotten. We tested whether a state rotation model would help students to recall key principles of Cardiovascular Physiology (CV). **Methods:** Seventy-one undergraduate students enrolled in the Exercise Physiology Course at the School of Physical Education and Sport, University of São Paulo, participated in the study. The students were randomly assigned into one of 4 stations, dedicated to recalling the concepts of the heart as a pump (e.g. preload, post-load, and contractility; station 1) and hemodynamics (e.g. serial and parallel conductance; station 2) by using the educational tool. Heart rate (HR) control by sympathetic nervous system activation (station 3) and HR control by vagal activation (station 4) were assessed by quantifying HR response to the Stroop color and word test and during face immersion in cold water, respectively. To evaluate the efficacy of the intervention, we used a *Socrative* app to launch eight multiple-choice questions before (PRE) and after (POST) the student's station rotation. The questions were related to the basic principles of exercise physiology and its consequences on the cardiovascular system. **Results:** The 4-station average score (% of corrected answers) achieved after the station rotation was higher than the score achieved before (71.21%, SD 14.50 vs. 31.07%, SD 18.04; for POST and PRE, respectively $p < 0.005$). Considering specific stations, the lowest score of corrected answers before the rotation was observed at station 2- hemodynamics when compared with station 1-heart as a pump and station 3/4 - autonomic control (18.9%, SD 0.9 vs. 46.5, SD 24.1 and 34.8, SD 2.1 for hemodynamics, heart as a pump and autonomic control, respectively). Interestingly, after the rotation, there was a significant increase in corrected scores for all stations (33.9, SD 9.8; 80.5, SD 4.6 and 90.2, SD 2.3, for hemodynamics, heart as a pump, and autonomic control, respectively). **Conclusion:** Our results suggest that the use of the educational tool was effective to recall CV principles that are essential to a better understanding of the CV responses to exercise and applying the concepts in exercise testing and prescription for different populations.

Keywords: cardiovascular physiology, exercise physiology, cardiovascular system, teaching strategy.

Introduction

Physical exercise is known to induce several acute and chronic cardiovascular responses[1,2]. In order to understand these responses, undergraduate students in Physical Education and/or Sport Sciences need to understand basic concepts of cardiovascular physiology, such as the heart as a pump, the basic concepts of hemodynamic, and the autonomic control of the cardiovascular system[3]. Without acquiring these skills on solid basic science knowledge, their expertise might be questioned in the future[4,5].

For instance, taking into consideration the heart as a pump, students must understand concepts as cardiac output (amount of blood the heart pumps through the circulatory system in a minute), stroke volume (blood volume ejected when the heart pumps in a contraction), and its determinants (preload: load on ventricular muscle at the end of diastole; afterload: difficulty faced by the ventricle when ejecting blood; contractility: intrinsic strength of the cardiac muscle independent of preload and afterload) and heart rate (number of contractions/beats per minute). In hemodynamic, students need to understand the concepts of peripheral vascular resistance (resistance to blood flow offered by the systemic vasculature), blood pressure (the pressure of circulating blood on the walls of blood vessels), and blood flow (movement of blood through the cardiovascular system). Regarding cardiac autonomic control, the students need to know the basic principles of how the sympathetic and parasympathetic nervous systems modulate cardiovascular function.

Students typically report exercise physiology as one of the most difficult disciplines to learn[4-7], and this might be related to low retention of previously taught basic physiology concepts. Therefore, strategies to recall the main cardiovascular physiology concepts are of paramount importance for students enrolled in exercise physiology classes. In this sense, hands-on learning with a station rotation approach is considered a teaching strategy in which small groups of students move through a series of stations to learn by doing an experiment or using an equipment. Therefore, this kind of strategy may help students to learn important concepts as observed in studies[8], and we presently used this strategy to recall basic cardiovascular physiology concepts.

In the present study, we have tested the use of educational tools for recalling/teaching basic cardiovascular physiology concepts. We hypothesized that the use of the didactic tools would improve the Physical Education and Sport Science students to recall of cardiovascular physiology concepts.

Methods

Participants

This study was approved by the School of Physical Education Research Ethical Board (CAAE: 12242919.9.0000.5391) in accordance with the 1964 Declaration of Helsinki amendment in 2013. Each participant provided written informed consent before enrolling in the study. Participants were 71 (30% females and 70% males) second-year students of the Bachelor degree program of both Physical Education and of Sport Science at the University of São Paulo (EFEE-USP) enrolled in the Exercise Physiology course. Exercise Physiology at EEFE-USP is a core course for both bachelor's degrees.

Experimental design

According to the Exercise Physiology Course Schedule, out of 15 lectures, the 5th lecture was chosen to conduct the data acquisition, since it includes a topic (basic concepts in cardiovascular physiology, Figure 1) often forgotten by the students. At the beginning of the class, right after agreeing with the informed consent, the students were invited to log in at the virtual classroom using the Socrative App (https://socrative.com/apps/) and to answer eight questions (Table 1) related to key concepts in cardiovascular physiology and autonomic heart control (baseline measure; PRE). Socrative is a quiz-based, formative assessment tool with multiple features that can enrich teaching and learning, which allows teachers to design quizzes, multiple-choice questions, etc. The questions were originally prepared by one of the teachers (PCB), except for question number 4 extracted from the review by Belloni FL[9]. The answers in the app were set in a multiple-choice format (five options ranging from "a" to "e"). The students were informed about the questionnaire at the informed consent, which occurred immediately before the questionnaire application.

After answering the questions at Socrative App, students were randomly assigned into 4 smaller groups. Each

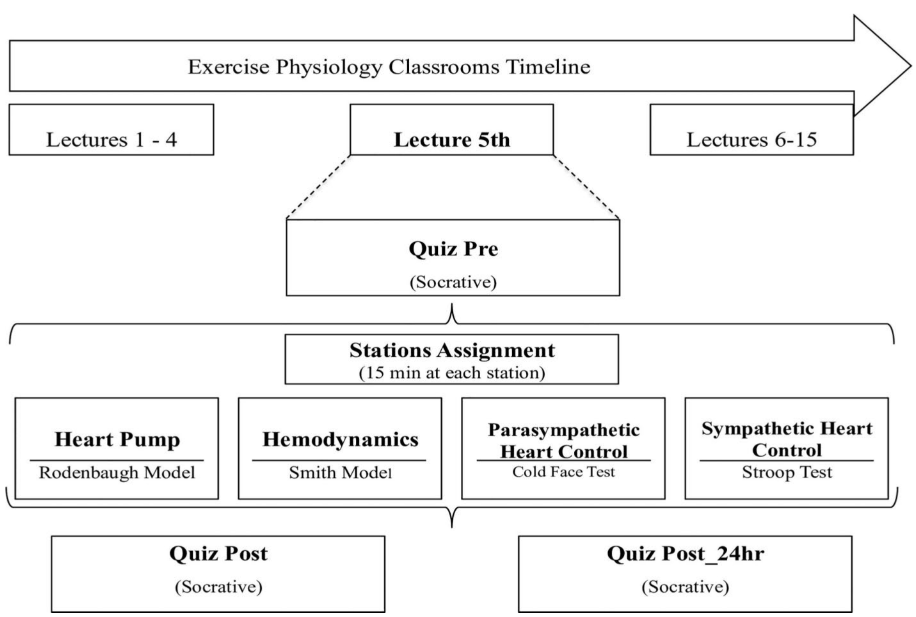
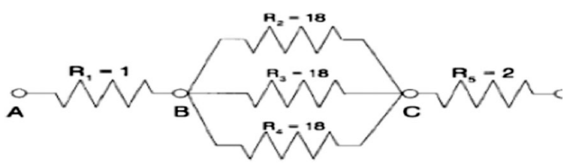


Figure 1 - Schematic representation of the experimental design.

Table 1 - Questions used in knowledge retention test.

Questions	Correct answer	Concept
1. What is preload? In your opinion, what kind of exercise would lead to preload increases?	Preload is proportional to the volume of the ventricle, the force or stress of the muscle before	Heart as a Pump
2. What is post-load? In your opinion, what kind of exercise would lead to intermittent post-load increases?	Post-load is proportional to the mechanical load that opposes ventricular ejection. The force and static exercises increase the afterload.	
3. What is cardiac contractility? What happens with cardiac contractility during exercise?	It is the property of the heart muscle that determines its ability to contract (contractile force) independent of pre- or post-load. Cardiac contractility increases with exercise.	
4. Use the picture below to answer the questions. The pressure at A (BP) = 90 mmHg and DPB = 0 mmHg. The resistances for R1-R5 are next to each vessel (mmHg.min) a) What is the flow through this vascular system? b) What are the pressure values at points B and C? c) If R4 undergoes a total occlusion, what will be the flow in the vascular system? 	a) 10 mL/minb) B = 80 mmHg and C = 20 mmHgc) = 7.5 mL / min	Hemodynamics
5. What do you think happens to blood pressure, cardiac output, and peripheral resistance during dynamic treadmill exercise	Increases, increases and decreases, respectively.	
6. When there is activation of the sympathetic nervous system during exercise:	Heart rate increases as well as myocardial contractility through the interaction of Noradrenaline (neurotransmitter) with cardiac beta-adrenergic receptors.	Sympathetic Heart Control
7. When there is activation of the parasympathetic nervous system (i.e. immersion of the face in cold water):	Reduction of heart rate through the interaction of acetylcholine (neurotransmitter) with cardiac muscarinic receptors.	Parasympathetic Heart Control
8. If cardiac innervation is sectioned, the heart:	Heart will contract more frequently	Sympathetic Heart Control

group was instructed to rotate through 4 stations (station rotation model). Each station had one instructor (teacher or teaching assistants) responsible to teach one of the four concepts: the heart as a pump (station 1, S1), hemodynamic (station 2, S2), sympathetic (station 3, S3), and parasympathetic (station 4, S4) heart rate control (Figure 2). After station rotation, students were invited to answer the same 8 questions (baseline; POST). The data collection was conducted in April-2019.

Procedures

At the S1, students were introduced to the model proposed by Rodenbaugh et al.[9]. Through this model, it is possible to explain the main concepts of the heart as a pump (cardiac output, stroke volume, preload, and afterload). This model provides to students an easy way of understanding cardiovascular mechanics, promoting student interaction and discussion of cardiovascular principles.

At S2, students were explained the basics of hemodynamic (pressure, flow, and resistance relationship). For this, we have built the model of the circulatory system proposed by Smith[10]. Using this model, students can investigate the effects of blood volume, vein compliance, arterial and vein constriction, heart pumping, and blood pressure. The system also demonstrates the effect of arterial diameter on resistance and flow velocity[11].

The 3rd and 4th stations were dedicated to autonomic control of heart rate. Different maneuvers were used to stimulate the vagal or sympathetic nervous system. At the 3rd station, we applied the Cold Face Test (CFT). The test consists of the face's immersion (forehead and maxillary) in a bowl of water and ice until volitional abandonment. Beyond other mechanisms, this test activates the cardiac parasympathetic nervous system leading to bradycardia[12]. One student was invited to perform the test. After wearing a heart rate monitor, the participant was verbally instructed to hold breath and place the face in the cold water and

Figure 2 - Representative pictures of the students at the 4 stations. A) Hemodynamic; B) parasympathetic nervous system; C) heart as a pump and D) sympathetic nervous system.

stay immersed as long as possible. Maximal bradycardia is reached between 40 and 60s[12]. All group members observed bradycardia in response to the CFT.

In the fourth and last station, a stressful test was used (Stroop color and word test). In this test, four words (red, blue, green, and yellow) were written on a paper with inconsistent color ink (for instance the word "red" is printed in green ink). A voluntary student was required to name the color of the ink instead of reading the word, as quickly as possible. Throughout the test, the student was wearing a heart rate monitor to evaluate heart rate responses during the test. Stroop Test is considered a stress test that activates the sympathetic nervous system leading to tachycardia and has been used extensively used as a mental stress test and cognitive test[13].

After completing the stational rotation, students were invited to log in to the virtual classroom using the Socrative App (https://socrative.com/apps/) and answer the same eight questions (Table 1) involving the key concepts in cardiovascular physiology and autonomic heart control (baseline; POST). The answers in the app were set in a multiple-choice format (five options ranging from "a" to "e"). The percentage of correct answers pre (%PRE), of correct answers post (%POST) and [delta (Δ) = %POST - %PRE) was calculated. The Socrative App presents the final score for the questionnaire in the percentage of correct answers stratified by students and by questions.

Statistical analysis

Descriptive data of participants were expressed as mean (M) and standard deviation (SD). Percentage of increase or decrease between PRE and POST conditions was reported. The student's grade was stratified into very high (above 7 corrected answers – top 10%); high score (between 5 and 8 corrected answers - top 35%); and low scores (below 5 corrected answers - under 60%) considering PRE vs. POST conditions. The normality of the data distribution was checked using the Shapiro-Wilk test. Differences in moments (%PRE vs. %POST) were compared by the Wilcoxon Signed Rank test for related samples since non-normal distribution was achieved by the Shapiro-Wilk test. The magnitude of the effect [effect size measurements (ES, Cohen's d)] was calculated and classified according to the criteria suggested by Batterham and Hopkins[14] as follows: < 0.1 = trivial; 0.1-0.3 = trivial/

small; 0.3-0.5 = small; 0.5-0.7 = small/moderate; 0.7-1.1 = moderate; 1.1-1.3 = moderate/large; 1.3-1.9 = large; 1.9-2.1 = large/very large and > 2.1 = very large. Data were analyzed using SPSS Statistics 24 (Chicago, IL, USA) and the significance was set at 5% ($p < 0.05$).

Results

The station rotation using physiological tests and educational tool (POST) significantly increased student's correct answers (% score) when compared with PRE-condition (71.2, SD 14.5 vs. 31.0, SD 18.0; $p < 0.001$; ES 2.4, very large), which represented 129.19% of the increase (Figure 3).

In the PREcondition, only 5 (7%) out of 71 students, displayed high scores on the test while the majority of the students displayed low scores 66 (93%). None of the students reached very high scores (> 7 correct answers). Conversely, students' performance in the POST condition was significantly improved. Out of 71 students, 17 (24%) and 49 (69%) reached very high and high scores, respectively, while only 5 (7%) students displayed low scores.

Concerning the concepts, the students presented lower values of corrected answers in hemodynamics (18.9, SD 0.9 and 33.9, SD 9.8, for PRE and POST test condition, respectively) than autonomic control (34.8, SD 2.1 and 80.5, SD 4.6 for PRE and POST test condition, respectively) and heart as a pump (46.5, SD 24.1 and 90.2, SD 2.3 for PRE and POST test condition, respectively).

Discussion

The main finding of the present study was that the use of the station rotation model with educational tools was efficient in helping students to recall key concepts related to basic cardiovascular physiology, corroborating our hypothesis. Indeed, 93% of the students obtained very high or high scores of correct answers in the post station rotation (POST condition).

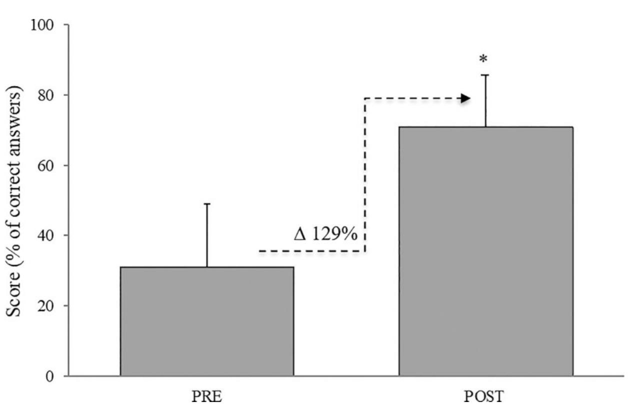


Figure 3 - Percentage of correct answers PRE and POST station rotation. Data are presented as mean ± standard deviation. * = Significantly higher than PRE ($p < 0.001$).

Several strategies have been recently applied to improve the physiology education of undergraduate students[15]. Presently, we combined methodologies based on educational tools and physiological tests with a multiple-choice questionnaire strategy at a mobile-phone online platform. As far as our knowledge, this is the first study with an experimental approach combining active learning and a virtual platform for physiology teaching-learning with the objective of recalling basic concepts of cardiovascular physiology for exercise physiology students.

For a long time, the teacher was the only source of student's information and knowledge[16]. However, teachers must acknowledge the increasing student's interest in hands-on activities[17], which allows a better interaction of the students by handling instruments and manipulating objects they are studying[18,19]. We presently demonstrated that the hands-on activities with a station rotation used in our study are also feasible to recall concepts already taught. In fact, we noticed increased hands-on interaction during student's station rotation, which has led to a 129% increased score of correct answers in the after-rotation condition (Figure 3). This is of particular interest since a deep understanding of basic cardiovascular physiology is required to better understand acute and chronic cardiovascular responses to exercise and further interpret exercise testing and prescription.

Among the basic cardiovascular physiology concepts reviewed, students displayed higher difficulty recalling hemodynamics (pressure, resistance, and flow relationship) than the concepts of the heart as a pump and autonomic cardiac control. This might be because hemodynamics combines concepts of cardiovascular physiology and physics, as fluid mechanics. In this sense, the model of the circulatory system proposed by Smith[10] provided a more concrete, intuitive feel for hemodynamics that resulted in significantly higher scores in related questions post station rotations.

The basic science in different biological careers is often quickly forgotten. In fact, medical students in the senior clinical phase do not recall the basic concepts of physiology[20], and evidence indicates that the nonuse or nonpractice of previously taught knowledge and skills are directly related to the degree of the loss[21,22]. Moreover, some factors associated with retention of basic science knowledge among medical students are age (inverse relationship) and preparation for postgraduate course (direct relationship)[20]. Presently, we noticed heterogeneous backgrounds in basic concepts of cardiovascular physiology among our students when pre-intervention tests were analyzed. However, the teaching strategy adopted with educational tools and physiological practical tests improved the recall of basic cardiovascular concepts decreasing the heterogeneity of scores. We expect that after this recall, the students will be able to better apply this knowledge to better understand the cardiovascular responses to exercise.

We acknowledge some limitations in our study. We have not evaluated long-term knowledge retention in our study. Future studies should address knowledge retention after 24h or more hours after the intervention to have an idea of long-term knowledge retention. One might argue that we have not applied a validated questionnaire in the study; however, it is worth mentioning that the questions were multiple-choice, very specific, and straight to the point, decreasing the possibility of misinterpretations. Additionally, even though the same questions were applied before and after the station rotation, which could facilitate learning, we should clarify that our main objective was to help them to recall concepts already taught and the station rotation was a strategy for the students to recall the concepts in a hands-on manner, to increase the understanding and application of the cardiovascular concepts to exercise physiology.

Conclusion

Our results suggest that the use of educational tools and physiological tests for recalling principles of cardiovascular physiology was effective, providing evidence that this strategy can help with the learning of cardiovascular principles that are essential to a better understanding of cardiovascular responses to exercise. In this sense, our study encourages further studies assessing other teaching strategies to recall basic science are needed, especially the ones involving e-learning.

Acknowledgments

The authors are thankful to Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (#2016/19771-5 to D.S.O. and #2015/22814-5; #2016/50336-3 to P.C.B.) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (#306261/2016-2 to P.C.B.) for the financial support.

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Manuscript received on July 8, 2021
Manuscript accepted on November 12, 2021

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