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Learning Tennis through Video-based Reflective Learning by Using Motion-Tracking Sensors

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ABSTRACT: This study proposed a video-based reflective learning approach using motion-tracking sensors to facilitate the learning of tennis skills in a college physical education class by beginning players. The motion-tracking sensors, synchronized with a smartphone video application, were attached to tennis rackets for collecting the students' shot-data. By observing one's practice videos, students could compare their performance with the instructor's demo videos and reflect on the differences for possible improvement. A quasi-experimental method was conducted on two intact classes of students to investigate the effects of the proposed approach. The results showed that students taught by the proposed approach performed better than the traditional approach, exhibited positive attitudes toward learning, and obtained the essence of key tennis techniques. Future implementation should train students how to interpret the sensor collected shot-data so that students can have richer information for reflection.

Keywords: Sensors, Reflective Learning, Tennis, Physical Education, Video-based Learning

1. Introduction

Tennis is an enjoyable sport and often a favorite choice for students taking sports courses. It is provided as a physical education course on an elective basis for college students in Taiwan. Tennis is, however, a sport which students often find difficult to master because it requires the integration of multiple complicated skills. Most beginners have difficulty in mastering fundamental skills such as forehand and backhand groundstrokes. While performing a stroke, four critical temporal phases are involved -- preparation, backswing, forward stroke as well as the follow-through (Knudson & Elliott, 2004). The integration and application of these elements is often difficult for beginners-- it requires the combination of full-body coordination and proper timing of movements. Beginner group tennis classes ordinarily number between twenty and thirty students. As a result of the limitation of a two-hour class per week, students often do not get sufficient feedback from instructors to master the fundamentals of tennis. Even if feedback is provided, students often have limited opportunities to observe their movements—thus, students are unable to connect the feedback provided by the instructor with how they have performed in the class. Another major factor that has been discussed in existing research of sports learning was gender differences. Gender differences exist in motor skills acquisition, including tennis learning (Krumer, Rosenboim, & Shapir, 2016). Physical limitations and psychological tendency are two main reasons attribute to a gender difference in sports learning (Thomas & Thomas, 1988; Vilhjalmsson & Kristjansdottir, 2003). Physical differences such as body mass index (BMI) and muscular endurance benefit males' success in sports activities and therefore enhance their interests and confidence in sports learning. The difference in psychological tendencies affects students' beliefs and reflection quality in sports learning. A mixed-gender grouping is suggested to improve students' performance in physical education courses.

The importance of reflection has been addressed for both student learning and teacher training in physical education (Hanrahan, Pedro, & Cerin, 2009; Groves & O'Donoghue, 2009; Potdevin et al., 2018; Standal & Moe, 2013). Reflection is the process of an individual recapturing their experience, thinking about it, and assessing it. It is the capacity to apply prior experiences to improve subsequent performances in a goal-directed and effective manner (Zimmerman, 2000). A previous study showed that youth athletes who displayed a frequent use of reflection in their practices might attain more success later in their development (Jonker, Elferink-Gemser, de Roos, & Visscher, 2012). Reflection facilitated learners to become more aware of their strengths and weaknesses and help them compare the expected performance with their movements, thereby improving their sports techniques (Panteli, Tsolakis, Efthimiou, & Smirniotou, 2013). It also helped preservice physical education teachers to link their teaching experiences with pedagogical theories (Garrett & Wrench, 2008; Standal & Moe, 2013). However, Hanrahan, Pedro, and Cerin's (2009) study on sports learning found that the biggest complaint from students was the requirement to take time out from class to complete the reflection forms, and they suggested future study to complete the forms after the class.

To facilitate sports learners to recall the details of their previous performances, video-recording of the learner's movements during a practice session is necessary. Many studies have used video as viewable feedback to improve students' motor skills (Kretschman, 2017; Liebermann et al., 2002; Palao, Hastie, Cruz, & Ortega, 2015). Through the use of video-feedback, students pay more attention to the details of their performances, and better-applied the teacher's feedback to enhance their learning (Nowels & Hewit, 2018). Video-feedback enabled students to understand their performance and benefit from cognitive intervention techniques— especially when engaging in complicated motor tasks requiring power and coordination (Panteli, Tsolakis, Efthimiou, & Smirniotou, 2013). By observing one's practice video combined with the teacher's verbal feedback, students were better able to make significant improvements in their technique as well as having more high-quality practices in class (Palao, Hastie, Cruz, & Ortega, 2015). Potdevin et al. (2018) explored the impact of video-feedback on skill learning in a school-based physical education class. Their findings showed that providing video-feedback coupled with authentic performance data helped novice students reflect on their practice in class, thereby enhanced their gymnastic skills, self-assessment ability, as well as learning motivation. Yet, there were issues with the video-feedback approach-- it required additional teacher time for video recording, reviewing the video, and providing sufficient feedback on the performance. This usually slowed down the pace of instruction (Nowels & Hewit, 2018). By using wearable technology, the logistics of applying video-feedback can be greatly reduced.

With recent advances in IOT (Internet of Things) technology, wearable or ubiquitous sensors can be used to capture personal physical and psychological data in many fields, such as motor learning, language learning, health management, manufacturing processes, and biometric identification (Arif & Kattan, 2015; Blasco, Chen, Tapiador, & Peris-Lopez, 2016; Jou & Wang, 2015; Pan, 2017). In tennis learning, by analyzing and visualizing the information collected from motion capture devices or sensors could help learners better understand their shortcomings while practicing and prevent possible injuries (Oshita et al., 2019; Sharma et al., 2017). Having students access their personal data would facilitate meaningful reflection (Sobko & Brown, 2019). The shot-data of students while learning tennis can now be easily collected and analyzed by using wearable sensors. Büthe, Blanke, Capkevics, and Tröster (2016) used sensors to design a timing analysis system for tennis players. Martin, Bideau, Delamarche, and Kulpa (2016) employed sensors to collect and analyze kinematic, kinetic, and performance changes during prolonged tennis match play to provide quantified information of serve biomechanics. Many tennis sensors are now commercially available at reasonable prices, such as the Babolat Pop, Zepp Tennis Kit, Sony Smart Tennis Sensor, and the Qlipp Tennis Sensor. Some of the sensors have been shown to accurately measure strokes, shot type, ball speed, and hitting volume such as Sony Smart Tennis Sensor (Myers, Kibler, Axtell, & Uhl, 2019) and Babolat Pop (Raymond, Madar, & Montoye, 2019). These sensors detect and record a player's shots and wirelessly connect to smartphones and tablets to help provide information about a player's performance. Some sensors also allow data for each shot to be played back in synchrony with the corresponding recorded video. The slow-motion playback feature allows one to observe the moment of ball impact and check the students' swings as well as footwork. Students have the advantage of being able to reflect on their performances when sensors collecting shot data are paired with recorded videos.

Previous studies have shown the effects of video-feedback on learning tennis. Zheng's (2013) study of freshman beginner tennis classes indicated that video-feedback helped with the students' readiness to learn, ability to learn independently, and perceived deficiencies or incomplete instructor demonstrations. García-González, Moreno, Moreno, Gil, and Del Villar (2013) showed that the combination of video-feedback and questioning on cognitive expertise helped develop adaptations in long-term memory and improve the tactical knowledge of tennis players. Some conflicting results were reported in earlier studies. Emmen, Wesseling, Bootsma, Whiting, and Van Wieringen (1985) found no clear advantages for novices learning tennis when comparing video-feedback groups with the traditional group. However, they indicated, for the scores on form only (in addition to achievement scores), an almost significant interaction effect in favor of video-feedback. They conjectured that the non-significant effect might be due to the video display only providing knowledge of performance (movement information) but lacking a knowledge of results (information about the outcome of the tennis service). A similar study also found that intermediate tennis players gain no apparent advantage when the tennis service is trained to utilize video-feedback instead of traditional training (Van Wieringen, Emmen, Hoogesteger, Bootsma, & Whiting, 1989). This result might be because the video-feedback was not provided until all members of the group of subjects, who were trained together, had their services recorded. Thus, an improvement of the trainer-subject ratio could lead to a better performance for the video-feedback group.

Resulting from the limited empirical studies provided in the literature, the effect of video-feedback on learning/teaching tennis is inconclusive. In this study, we proposed a video-based reflective learning approach by using wearable technology (as described in Section 2.1) to assist beginners in learning tennis skills in a physical education class. This approach was intended to address the possible drawbacks of the previous studies. Instead of gaining limited feedback from instructors in a high student-instructor ratio group tennis class, this approach would provide students with quality self-reflective feedback. The tennis sensors attached to racquets could offer personal information about the outcome of the learner's shots synchronized with recorded videos. This study explored the effectiveness of our proposed video-based reflective learning approach. The research questions of this study are as follows:

- Does the video-based reflective learning approach using motion-tracking sensors help students learn tennis techniques?
- What are the students' attitudes toward the video-based reflective learning approach?
- How does the video-based reflective learning approach help students learn tennis techniques?

2. Research methods

In this study, we proposed the video-based reflective learning approach based on the literatures surveyed above. A quasi-experimental study was then conducted in order to investigate the effects of the proposed approach. The approach, participants, research instruments, procedures as well as data collection and analysis are described below.

2.1. The Video-based reflective learning approach

Our approach integrated the application of video-feedback, reflective learning, and wearable technology into the teaching of beginner group tennis in a PE setting. The use of video-feedback facilitated students to observe the details of their performance (Nowels & Hewit, 2018) and benefited from cognitive intervention techniques (Panteli, Tsolakis, Efthimiou, & Smirniotou, 2013) such as reflective learning. Reflection enabled students to learn their strengths and weaknesses and helped improve sports skills (Panteli, Tsolakis, Efthimiou, & Smirniotou, 2013). By providing both student's practice videos and the instructor's demonstration videos, students were able to compare their differences with the instructor and came out with improvement ideas. The motion-tracking tennis sensors synchronized video-feedback with the authentic performance data helped students reflect on their practice (Potdevin et al., 2018). In addition, our reflective activities were arranged online and after class to avoid the problem of occupying class time, as reported in Hanrahan, Pedro, and Cerin's (2009) study. We described the details of our approach below.

A typical two-hour group tennis session ordinarily consists of the following stages: (a) Demonstration-- the instructor explains and demonstrates the skills to be learned in the session, (b) Practice-- students practice the skills and the instructor and TAs provide feedback, (c) Wrap-up-- the instructor concludes the session by pointing out common problems students have and re-demonstrating the skills, and (d) After-class activity-- students do assignment after class, for example, watching the instructor's demonstration video on the Internet and answering questions. The proposed video-based reflective approach differed from the traditional approach in two folds (Figure 1). In the Practice stage, we used tablet computers, which synchronized with the tennis sensors, to film the students' practice videos and collect their shot-data as well. The instructor (and/or the TA) then gave students video-feedback onsite. In the After-class stage, students engaged in the reflective process by viewing videos and answering self-assessment questions on a Moodle system. The implementation of both Practice and After-class stages in this study is as follow.

In the Practice stage, students took turns using a racket attached with a sensor. Each student was filmed for approximately 3 minutes. The shot-data, including ball spin, swing speed, swing type, impact position (such as *sweet spot*) and ball speed, could then be displayed in real-time on a smartphone or tablet via Bluetooth. By using the app of the sensor, the students could check the information of each shot they had practiced (see Figure 2). The instructor and/or TAs could then offer immediate feedback onsite. After the class, the TAs would upload the instructor's demonstration video (Figure 3) along with each student's practice video onto the Moodle system for later use on the After-class reflective activity.

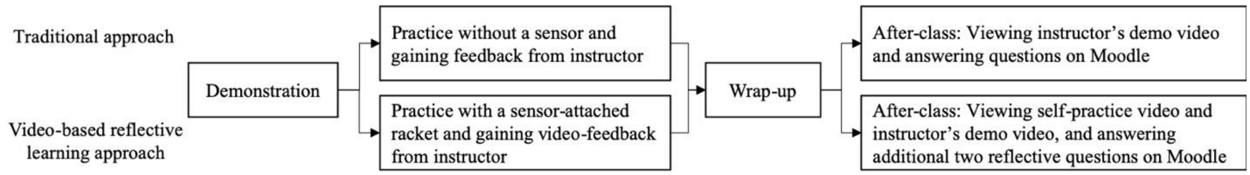

Figure 1. The video-based reflective learning approach vs. the traditional approach

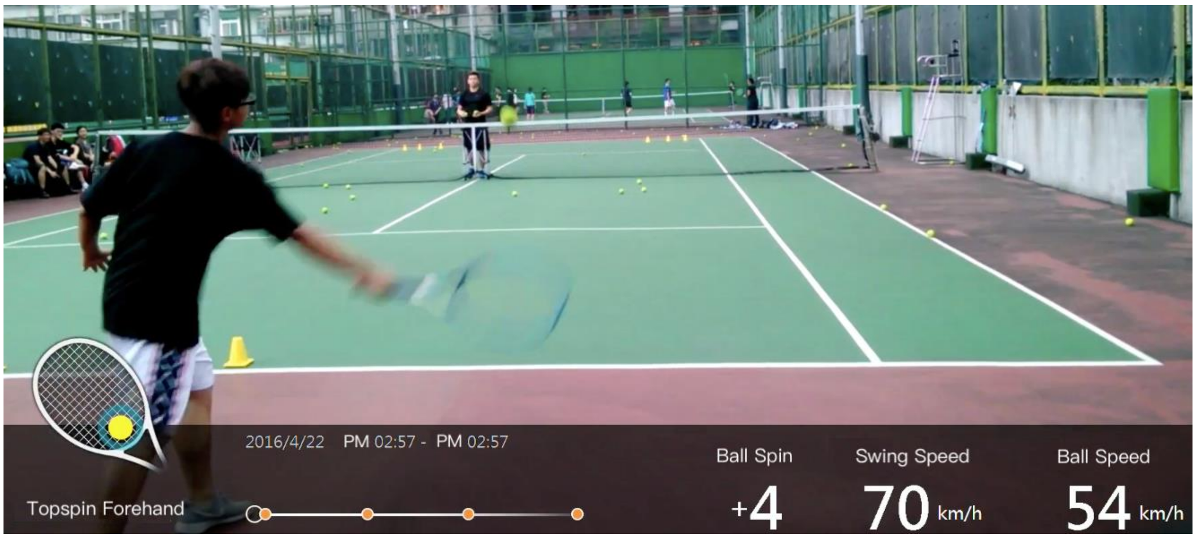

Figure 2. An example of student's shot-data on the practice video

Figure 3. An example of the instructor's shot-data on the demonstration video

At the After-class stage, students were required to engage in a reflection activity on the e-class Moodle system of the university. To place students into the reflective process, students were asked to answer two questions. The first question was, "What skill-related problems have you experienced in class this week?" which provoked students to assess their performance by observing their practice videos. The second question was, "Write down the areas in which you feel that improvements could be made." which enabled students to examine and compare their postures and movement with those of the instructor, as shown in the student's practice video and the instructor's demonstration videos. For example, a student might find that he or she did not hit the sweet-spot area of the racket (Figure 2, left bottom corner). The student could then compare his or her techniques with those of the instructor (Figure 3, left bottom corner). Students could, additionally, read the shot-data of their swing speeds and ball speeds and find them to be far lower than that of the instructor. A necessary component of the instructional approach is to allow the instructor and TAs to interact with students on the Moodle after the class. Detailed advice about their performances can then be provided to students to improve their skills (see Figure 4). To prevent improper comparisons or judgement among students that might result in incorrect causal attribution (Zimmerman & Campillo, 2003) as well as to keep students' performance private, students were only allowed to view their own reflections, practice videos, and corresponding comments given by the instructor or the TAs.

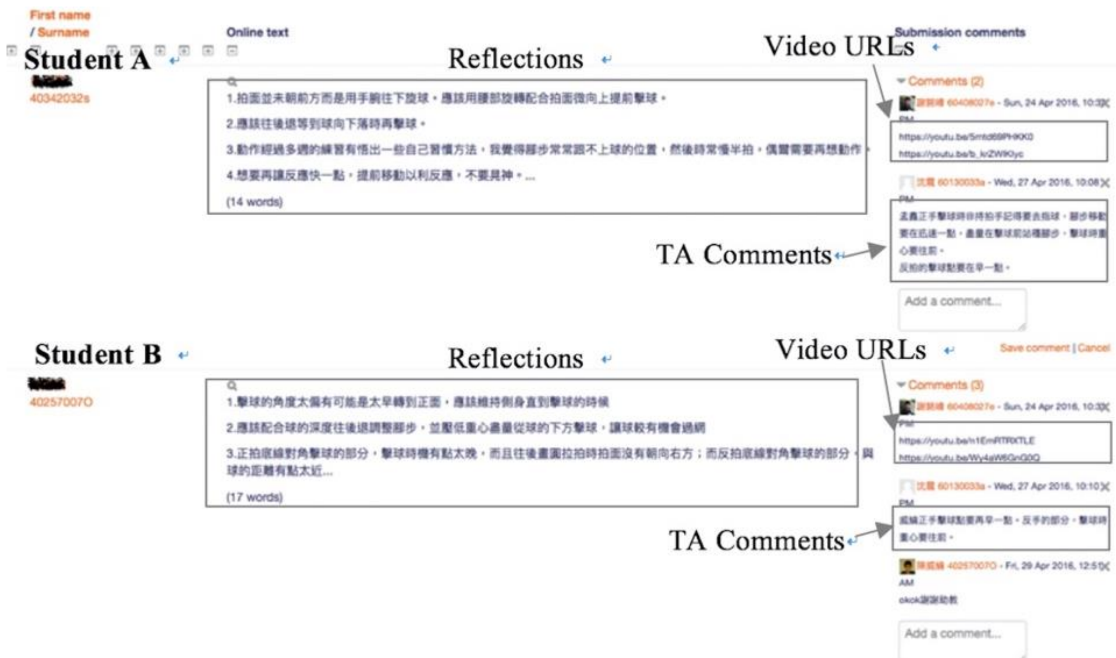

Figure 4. TA's comments on students' reflections on the Moodle

The reflection mechanism in this study (Figure 5) was designed based on Zimmerman and Campillo's self-regulation model (2003). After the practice stage, students were guided for reflection based on their practice videos, instructor's demonstration videos and the corresponding shot-data (video feedbacks). Two reflective questions served as the prompts to facilitate students' self-evaluation and casual attribution process. Students then could get feedbacks from the TAs. After the reflective process, students would be aware of their deficiencies timely and based on which they would develop ideas about posture adjustment for improving their performance. Another learning cycle then restarted from the next practice, ideas generated in the last reflective process helped students focus on their postures and re-exam the effectiveness of their posture adjustment plans.

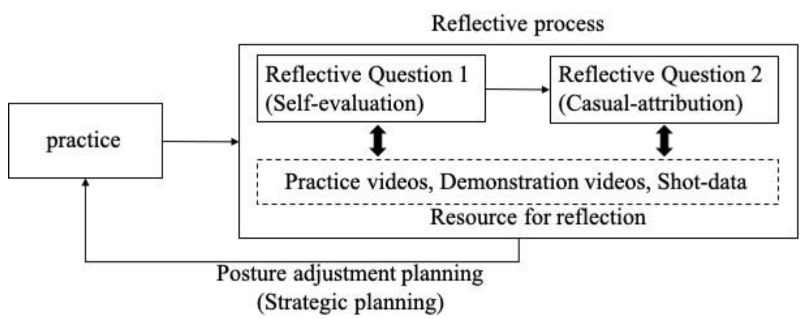

Figure 5. Reflection mechanism in the video-based reflective learning approach

2.2. Participants

The participants in this study were two intact classes of college students who took the PE beginner tennis course at the university. One class with 32 students served as the experimental group and applied video-based reflective activities during instruction. The other class with 30 students served as the control group, applying a traditional approach. After excluding students with high rates of absenteeism, the experimental group consisted of 25 students (10 males and 15 females) and the control group consisted of 25 students (18 males and 7 females). The PE course is required for all students at the university but students can select the sport and level of their choice. Students of the two classes were all beginning players. The instructor explained the purpose, methods, and possible risks of this study to all students at the first class. Students could decide to participate or not, and their decisions would not affect the evaluation of their performance. All participants in this study were over eighteen years old and consented to the research process.

2.3. Research instruments

The research instruments included tennis sensors, Moodle, tennis performance tests, and an attitude questionnaire. We selected the Sony Smart Tennis Sensor for use in our instructional approach. The Smart Sensor, which has been approved by the ITF (International Tennis Federation) for tournament use (ITF, 2014), is an accurate way of measuring hitting data in tennis and can be used by coaches to track player's performance (Myers, Kibler, Axtell, & Uhl, 2019). It equipped with Bluetooth and two different sensors, a 3-axis motion-tracking sensor tracks the movement of the racket, and a vibration sensor acquires data on the strength and the point of impact on the racket head. The sensor, weighing approximately 8 grams, is designed to attach to the grip end of a racket. It is compatible with several tennis racquets; among them, we chose the Head Graphene XT Instinct S racket. Rather than using a smartphone, we used a tablet, the ASUS Transformer Pad TF701T, to support the app of the sensors. The large screen of a tablet allowed for easier viewing during class time so that the instructor could provide students with immediate feedback. In addition, the motion tracking sensors adopted in this study would not collect any individual's biological information or jeopardize the students' health and safety. The Moodle system served as an e-learning platform for the after-class learning activities. Besides delivering instructor's demonstration videos and weekly assignments, Moodle also allowed students in the experimental group to access their practice videos, write reflections, and obtain the corresponding feedback given by the instructor or TAs by using the online texting function (see Figure 4).

Performance tests and an attitude questionnaire were administered to the tennis classes in order to assess the learning outcomes of the students. The performance test was based on the Groundstroke Accuracy Assessment of the International Tennis Number (ITN) scoring standards (ITF, 2004). Four types of skills were assessed in this study, including forehand crosscourt, forehand down the line, backhand crosscourt, and backhand down the line. Five shots were allowed for each of the four skills-- for a total of twenty shots. Each shot was assessed for accuracy, power, and stability. Scores for each shot ranged from zero to seven with a possible maximum score of 140 points. The performance test has clear scoring rubrics based on where the ball lands on the first and second bounce. In addition, each shot of scoring can be correctly judged by the instructor and confirmed with the other two TAs to ensure its reliability.

A ten-item attitude questionnaire (see Appendix) was developed to measure the effects of the proposed video-based reflective learning on students' learning in tennis. Since self-efficacy and intrinsic interest play an important role in sports learning and self-reflection processes (Zimmerman, 2000), these factors were included in the design of the questionnaire to understand students' confidence about their skills (questions 1 & 2), the usefulness of the instructor's demonstration videos (questions 3 & 4), and students' interests in learning tennis (questions 8, 9, & 10). The experimental group was asked three additional questions (questions 5, 6, & 7) related to the video-based reflective activities. Answers to questions used a Likert-type scale, ranging from 1 point (strongly disagree) to 5 points (strongly agree). The questionnaire was reviewed by two tennis educators and two measurement academics to ensure validity. The Cronbach's α values for each dimension ranged from .60 to .83, indicating acceptable reliabilities.

2.4. Procedures

Both classes were held once a week over an 18-week period. Each week had a two-hour class session. All of the course content, teaching schedule, and the instructor and the two TAs were the same for both the control and experimental groups. In each session, both groups of students went through the four instructional stages, as described in Figure 1. The differences between the two groups were that students in the experimental group had video-feedback during the Practice stage. They were able to view their practice videos in addition to the instructor's demonstration videos provided for both groups, and were required to answer two additional questions for the reflective process on Moodle. The control group did not have access to tennis sensors to incorporate the use of practice videos for reflection; however, they were also required to login into the Moodle to answer three to five tactic knowledge questions related to the skills taught during the week, for example, "Which direction should the racquet head face when hitting a ball?" The same questions were also given to the experimental group.

Due to rainy weather conditions and sessions for mid-term and final examinations, students in the experimental group used tennis sensors for a total of 11 weeks. Six of these weeks focused primarily upon forehand and backhand shots and included self-reflective questions. Classes were held on two outdoor tennis courts. On those days where rain prevented outdoor play, students practiced inside a gymnasium or spent time watching instructional or professional tournament videos. At the last lecture of this course, both groups of students were asked to take the performance test and complete the attitude questionnaire. This study did not conduct a pre-test to assess students' performance because all the participants were novice tennis players.

2.5. Data collection and analysis

The data collected for this study were the students' tennis performance test scores, answers to attitude questionnaires, and answers to the instructor's questions on the Moodle. The ANOVA test was conducted to test the performance difference between the two groups. Gender differences have been previously shown to have some effects on student performance in sports (Krumer, Rosenboim, & Shapir, 2016; Thomas & Thomas, 1988; Vilhjalmsson & Kristjansdottir, 2003). As the experimental and control groups had unequal numbers of males and females, a two-way ANOVA was used to account for gender as a possible factor in affecting student performance. The ANOVA test was then conducted to investigate how different learning approaches affect the students' attitudes toward learning. To explore how and why the reflective activities may have affected the students' learning, the answers to the reflective questions provided by the students on Moodle were analyzed and also served as supporting evidence to explain the statistical results.

3. Results and discussions

3.1. Learning performance

Descriptive statistics regarding the student's performance test scores are presented in Table 1. The data showed that students in both groups (control and experimental) averaged somewhere between 20 and 40 points on their performance tests. This score is significantly below the maximum score of 140 points but is common for beginners. On average, students missed half of the 20 balls in the test (the experimental group missed nine balls, while the control group missed 10.2 balls). For each successful shot, students often scored four or lower points (out of seven) due to a lack of ball power.

The results of the ANOVA analysis regarding student performance are presented in Table 2. Partial Eta Squared ($\eta p2$) is presented as a measure of effect size. A $\eta p2$ value between .01 and .06 is classified as a small effect, between .06 and .14 as a medium effect, and .14 or higher as a large effect (Warner, 2012). The analysis showed no significant interactive effects between the gender and the group factors ($F(1, 46) = 3.90$, $p = .05$, $\eta p2 = .08$). Significant differences with a medium effect were observed between experimental and control groups, as well as observed differences between male and female performance. The experimental group performed better than the control group ($F(1, 46) = 6.35$, $p < .05$, $\eta p2 = .12$) and the male students outperformed the female students ($F(1, 46) = 5.08$, $p < .05$, $\eta p2 = .10$) on the performance test. The results suggest that the video-based reflective learning approach was effective. The result of the gender difference is in accordance with previous studies (Thomas & Thomas, 1988; Vilhjalmsson & Kristjansdottir, 2003).

Table 1. Descriptive statistics for students' performance assessment

	N	*M*	*SD*
Group			
Experimental	25	39.80	12.70
Control	25	34.20	12.54
Gender			
Male	28	39.14	11.58
Female	22	34.27	14.02
Group X Gender			
Experimental/Male	10	40.40	12.76
Experimental/Female	15	39.40	13.09
Control/Male	18	38.44	11.19
Control/Female	7	23.29	9.01

Table 2. The ANOVA results on students' performance assessment

Source	*SS*	*df*	*MS*	*F*	*p*
Group	894.38	1	894.38	6.35^{*}	.015
Gender	715.20	1	715.20	5.08^{*}	.029
Interaction	549.11	1	549.11	3.90	.054
Error	6481.87	46	140.91		

Note. $^{*}p < .05$.

3.2. Attitudes toward the learning activities

Table 3 shows the ANOVA statistical results on student perceptions of the learning activities. Both groups of students showed a medium level confidence on their skills, with a mean around 3.5; and high interest in learning tennis, with a mean above 4.5. There was no difference between the two groups on their confidence in skills (F(1, 56) = .87, *p* = .35, ηp2 = .02) and interest in learning (F(1, 56) = 2.76, *p* = .10, ηp2 = .05). Although students in both groups showed an interest in enrolling in future tennis classes (question 10), the score of the control group (M = 4.70) was higher than the experimental group (M = 4.39). We speculated that students in the experimental group were less inclined to enroll in tennis courses in the future due to the fact that the video-based reflective approach required additional time and effort as found in the previous studies (Hanrahan, Pedro, & Cerin, 2009; Nowels & Hewit, 2018). They had a comparatively heavier homework load for answering self-reflection questions, and spent more time accommodating the use of sensors in class, as compared to the control group.

As to the effects of videos, both groups perceived the benefit of the instructor's demonstration video, the experimental group showed significant positive attitudes than the control group (F(1, 56) = 5.31, *p* < .05, ηp2 = .09). This difference may be because students in the control group were only provided with the instructor's demonstration videos. They were unable to view videos of themselves practicing, which could then act as a basis for comparison with the instructor's demonstration videos. Students in the experimental group, on the other hand, were required to answer self-reflection questions, and were more inclined to view both their own and the instructor's demonstration videos. Students in the experimental group, consequently, were shown to value the instructor's demo videos more highly than the control group.

In addition to the results on Table 3, students in the experimental group were asked additional three questions about the reflective activities. The overall satisfaction level of the students was high, being over four points out of a maximum of five. Students agreed using techniques such as watching their own practice videos (question 5, M = 4.32), corresponding shot-data (question 6, M = 4.16), and TA feedback (question 7, M = 4.16) would be helpful in learning tennis skills. Note that the numbers of students (N) in Table 3 are slightly different from those in Table 1. It is because the attitude questionnaire was conducted at the end of course survey and was filled out anonymously, thus the statistical analysis could not exclude students with high rates of absenteeism.

Table 3. The ANOVA results on students' attitudes toward the learning activities

Dimension	Group	*N*	*M*	*SD*	*F*	*p*
Confidence in skill	Control	27	3.59	.83	.87	.35
	Experimental	31	3.40	.71		
Video effects	Control	27	4.26	.54	5.31^{*}	.03
	Experimental	31	4.58	.52		
Interest	Control	27	4.75	.38	2.76	.10
	Experimental	31	4.53	.58		

Note. $^{*}p < .05$.

3.3 Students' reflection on the Moodle

To explore what kinds of technique problems the students reflected on, six weeks of student answers to reflective questions on Moodle, which focused on the forehand and backhand shots, were collected and analyzed. A total of 135 posts were analyzed by two raters (the first and the third authors) based on the six critical tennis techniques taught in class. Both of the raters reviewed all the posts and discussed the discrepancies between their analysis to reach agreement. Since each post might cover more than one technique problem, we counted the number of times that each key technique was mentioned in the answers by students and calculated a total of 248 mentions. The percentages of each technique mentioned are presented in Table 4. Overall, the most significant problem that students encountered was related to their tennis form. Students felt that the major reasons for making poor shots stemmed from their inability to control their wrist and/or racket angle (technique 1, 24.19%) as well as an uncompleted swing path (technique 2, 24.19%). How to execute the proper timing when hitting a ball (technique 3, 23.79%) and maintaining balance of body (technique 4, 20.56) were also common challenges for tennis beginners. It was found that most of the reflections were key tennis skills that the instructor addressed in the class, only about 6 percent of posts related to other issues (technique 7) such as control of swing speed, their expectations for improvement, or feels about their performance. This demonstrated that the proposed approach promotes student engagement in meaningful reflection and active thought. By examining their own techniques, which were subsequently compared to the instructor's demonstration video, students were able to discover flaws in their skills and devise methods for improvement.

On the other hand, less than one percent of the reflections mentioned problems related to hitting the ball on the sweet spot (technique 5) or identifying the flight trajectory of an approaching ball (technique 6). The technique of hitting on the sweet spot involves many issues such as the timing or the racket angle for making a shot. Although the sweet spot information (and other shot data) was displayed on the practice videos, students often had problems to interpret the data and connect it to their form and movement; thus, resulting in very few reflections. For few reflections on the flight trajectory of an approaching ball, we found it was because that our camera was placed right behind the players-- which prevented us from video-taping the proper angle of the flight path of a ball (see Figure 2 and 3). Future implementation should address these problems.

Table 4. Percentages of students' reflection on the six key tennis techniques (*N* = 248)

Key technique		*N*	%
1.	Control of the angle of the wrist and racket when hitting the ball	60	24.19
2.	Whether the swing path is proper	60	24.19
3.	Proper timing for making a shot	59	23.79
4.	Maintaining balance and shifting the center of gravity of body	51	20.56
5.	Whether hitting the ball on the sweet spot	2	0.81
6.	Identifying the flight trajectory of an approaching ball	1	0.40
7.	Others (swing speed, expecations, emotions)	15	6.05

Below we present several reflective posts from students as supporting evidences on the effects of our approach--from simply observing and self-assessing on one's skills, to reflecting on one's skills and comparing those with the instructor. For example, a student observed that he failed to turn his body and hit the ball too late:

I didn't turn my body aside for a forehand shot, and hit the ball too late for a backhand shot. I have to make use of the strength from turning the body.

Or, one found that he did not hit a ball with proper timing and fail to control the angle of the racket:

I didn't hit the ball at the right time. The racket faced a little too up so that the ball flew too high. My posture is not correct for bringing the ball up for a drop shot. I have to practice more.

The advantages of examining one's performance in the practice video and comparing those with the instructor's (as shown in the demonstration video) were also addressed by the students. For example,

Because I didn't keep my racket facing forward (it faced up), the ball flew unstably. I also have to turn my body more to locate the center of gravity properly. In addition, my steps were not practiced enough. My postures were quite different from the instructor's.

Additionally, some students would compare their shot data (as in Figure 2) with those of the instructor's and conclude ways for improvement. For example,

The spin values of the instructor's hit were all +3, but mine were all +2, therefore I have to turn my body more. The swing speed of the instructor's hit were 57 and 53, respectively, but mine were 47, 48, and 49. I have to firm up my wrist. The ball speed of the instructor's hits were 35 and 33, but mine were 37, 40, and 41. Improper exertion increased the ball speed. The ball speed should be transferred to spinning. I have to practice more to grasp the skills.

The results echo previous study where self-explanation practice prompts the students to recognize links between the knowledge or skills they have learned, and allows them to identify and address gaps in their understanding (Bisra, Liu, Nesbit, Salimi, & Winne, 2018). Students attributed their poor performances to the incorrect hitting postures based on both videos and TA's feedbacks, and planned for the next practice to correct the flaws. Moreover, some of students would compare their shot-data with the instructor's and conclude possible ways to adjust their postures. The reflective approach helped students to correct their hitting postures and improve their performance. However, the level of students' reflection might be a factor contributing to the effects, future studies should be conducted to investigate how students corrected their postures according to the reflections.

4. Issues regarding the use of sensors and videos

One factor that might limit the implementation of the use of sensors in beginner tennis classes is the cost. The ones utilized here cost approximately $200 each. Rackets utilized in the study were somewhat expensive, costing approximately $140 each. For many colleges and universities, equipment use might be expensive to implement fully, although the costs should decrease with increased demand. In the study, since current prices made supplying each student with equipment limited, we decided that students in each subgroup would share the use of sensors. Students used the sensors only during certain parts of the class period and this presented no major problems. It would be better if the sensors could be adaptable to a wider selection of rackets, eliminating the need to purchase new rackets to match various sensors. If individual users could enter their racket parameters, such as weight, length, and racket-face area, into the application, then the use of tennis sensors would be enhanced.

For conducting reflective activities on the Moodle, the students' practice videos had to be transferred from the tablets to a computer, and then uploaded to YouTube. Two potential problems were encountered which were the speed of the transfer and the time commitment. Transferring the videos from the tablets required using dedicated software (Sony PlayMemories) and each video had to be transmitted one-by-one. One component of the study was a requirement for adequate broad bandwidth and storage in order to view and to store videos of both the instructor's demonstration and the students' practice. The solution in the present study was to upload videos to a private YouTube channel, and then post each video's URL on the individual students' Moodle accounts, where files could be viewed by clicking on a link. The use of the YouTube format also allowed students to view their own practice videos in a timely manner. Transferring videos, uploading videos, and posting links all required additional time and effort from the instructor and TAs.

Some additional problems were encountered with the use of a built-in app designed for the sensors in the study. The app is designed for use by single users but not by multiple users. When sensors were shared by students, the app's "summary of all shot-data" read out as a single person's total statistics. This made it difficult to analyze overall performance from individual students in the group setting. One possible solution would be to install the app on each student's smartphone or tablet computer, then pair the sensor with a student's mobile device during their turn to use the sensor. Initially, this method would have added to the technical difficulty of installing and pairing the app as well as having taken longer to execute.

5. Suggestions for future implementation

In this study, students were able to view their shot-data in the practice videos, but additional time could have been spent on teaching students how to better interpret their shot-data information to improve their tennis form. For example, if students were able to pay special attention to the sweet-spot feedback (Figure 2, left bottom corner) for each shot, it would help them to understand where their problems lay. Students would find that not hitting the ball on the sweet spot usually had to do with their problems on shot timing, firming one's wrist, and racket angle. Furthermore, the sensor's feedback on ball-spin can also shed light on problems with the students' swing trajectories. Students should be taught to use the practice videos to compare their best and worst ball-spins and take steps to correct swing trajectory. Future implementation of using sensors should stress interpreting the shot-data information, which can serve as clues for reflecting on one's practice and comparing the differences with the instructor's form. In addition, filming videos from different shooting angles might help students observe and identify the flight trajectory of an approaching ball. Our study also exhibited a possible drawback indicated by Van Wieringen, and et al. (1989)-- the time span between performing the shot and receiving video-feedback was too long. Future implementation may either increase the TAs or re-schedule the flow of recording video and giving feedback. Reflection is important when learning proper sports techniques, but actual practice is an essential component following the reflection so that the reflected skills can be consolidated. In this study, most students were able to pinpoint their problems when in reflection, but improvements in form were limited because following-up practice sessions were not planned in our approach. Future implementation should place greater emphasis upon immediate practice on the court after students have watched and reflected on their practice videos. The time allotment for each phase may need to be adjusted to incorporate the reflect-then-practice strategy into the instructional approach. However, the level of reflection might also affect students' learning (Kember et al., 2000). Measuring students' reflection level will help investigate more deeply about the relationship between reflection and learning performance. Qualitative research methodologies (e.g., grounded theory research) might also be helpful for exploring implicit effects. Moreover, further study with larger sample size should be conducted to improve the external reliability of the results. Finally, to better control the video effects, students in the control group could also be provided with the self-practice videos so that the effects of videos could be balanced.

6. Conclusion

Learning tennis is often quite difficult because many factors come into play in the course of making a shot. Students are often unable to make proper judgments about running and hitting the ball during the time of play. Through the use of motion-tracking sensors and video-feedback, students could reflect on their own performance and compare those with the instructor's, which in turn helped them form better mental images and concepts about properly hitting a tennis ball. The results of this study showed that the experimental group had better learning outcomes than the control group, and was able to grasp the essence of key tennis skills-- hitting the ball at the appropriate time, controlling the wrist and angle of the racket, maintaining balance when swinging the racket, and whether the swing path is proper. The instructor's demonstration videos were particularly useful for the experimental group in that they were used to compare with the students' video-recorded performances and conduct their reflections. Since physical skills like playing tennis are not easy to be portrayed and explained clearly, the quantized and visualized data from sensors and videos could serve as an objective basis for student observation and comparison.

The use of sensors, videos, and self-reflection in this study was shown to be beneficial. For future implementation, we suggested that students could be trained to interpret the sensor's shot-data; video-feedback could be immediately followed the practice; follow-up practices could be scheduled immediately after reflections are completed, and the use of sensors should avoid interfering with the students' practice times.

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Appendix: Attitude questionnaire

Dimensions	Questions
Confidence in skills	1. I have confidence with my forehand.
	2. I have confidence with my backhand.
Video effects (and reflective activities)	3. Watching the instructor's demonstration video is helpful.
	4. I like comparing my playing with the instructor's playing on the demonstration video.
	5. Watching my practice video is helpful.*
	6. The shot information (sweet spot, speed, spin, etc.) shown on the video is helpful. *
	7. TAs' feedback on my reflections on Moodle is helpful. *
Interests in learning	8. I like the tennis class.
	9. I became more interested in tennis.
	10. I will continue to enroll in a tennis class.

Note. *Questions for the experimental group only.