11 Design and Evaluation of a Multimodal Virtual Reality Platform for Rowing Training

Emanuele Ruffaldi, Alessandro Filippeschi, Manuel Varlet, Charles Hoffmann, and Benoît G. Bardy

CONTENTS

INTRODUCTION

The advancements in virtual environment (VE) technologies, the improvements in models of motor control, and the availability of sophisticated data analysis techniques are all contributing to new practices in sport training. Classic training is now combined with new virtual reality (VR) training environments with specific feedback able to monitor performance, reduce training time, or allow training in places or moments in time not possible before. Rowing presents interesting research challenges and opportunities due to the combination of technique, strategy, and biomechanical elements, all contributing to performance. This chapter presents, from design to evaluation, the SPRINT research platform developed in the context of the SKILLS project. After introducing current research and training in VE, the SPRINT platform is presented. Then the results obtained in training specific skill accelerators on the platform are detailed.

SPORT TRAINING IN VIRTUAL REALITY

Assistive technologies have improved through the years, and today they contribute to increased physiological, biomechanical, or perception-action skills and provide coaches and athletes with fundamental information for shaping and programming training. Training in VR has received a great deal of attention in domains involving highly demanding cognitive tasks such as aeronautics or industrial maintenance (e.g., Aoki et al., 2007). The reduction of complexity of VR setups and the improvement in motion capture technology have allowed the extension of VR to physical training (Bailenson et al., 2008) and more interestingly for the present purpose to sport training, often using robotic and haptic systems (Multon et al., 2011). Research in sport training includes the investigation of complex skills in goal-oriented and task-oriented training situations (e.g., Wulf and Shea, 2002), as well as of specific perceptual or motor patterns. Bideau et al. (2003), Iskandar et al. (2008), and Vignais et al. (2010), for example, have developed simulated football scenarios for goal-keepers using immersive VR in order to evaluate how perception influences their decisions about when and how to move. In rowing, a similar approach has been proposed by Wolf et al. who recently, in parallel to this work, developed an immersive rowing system coupled with haptic feedback (von Zitzewitz et al., 2008). Rowing is an interesting sport in which VR training can be efficient due to the periodic and constrained nature of rowing action. Rowing requires athletes to be skilled in several areas to achieve a good level performance. Although it is difficult to rank them by order of importance, physical competencies are surely the most time-consuming skills to be developed, and rowing is often integrated with running and weight-lifting sessions. Skills such as rowing in team or mastering technique are seldom trained in a systematic way and are not continuously monitored. Coaches typically give advice about technique and team coordination verbally during training, with rare in-depth quantitative or qualitative analyses of the perceptual-motor behaviors involved. In sum, existing rowing training systems favor physical capabilities development over techniques or perceptual motor variables. The SPRINT system described in this work has been developed to train technique-based, perceptual, and physiological aspects of rowing using VR.

An initial task analysis for rowing (see Nolte, 2005, for details) led us to envisage three main training areas: technique optimization, energy management, and team coordination. Each area is composed of specific tasks (e.g., execute an efficient stroke, stabilize energy consumption, synchronize with other crew members), which are segmented in several subtasks (e.g., push with the legs, increase power output, apply more force at the inflexion point, etc.).

THE SPRINT PLATFORM

Design

SPRINT was designed to meet training needs, searching for the best compromise between variables useful for training and system complexity, and providing rowers with the same degrees of freedom and the same rigging settings they encounter in outdoor rowing. However, some boat degrees of freedom are not included, and force rendering is simplified in order to limit hardware complexity and portability. Similar decisions have been taken with software development, and features not directly involved in training were not introduced. The adopted design is highly modular, allowing future enhancement of existing parts and implementation of new parts at both the mechanical and software levels.

System

Trainees using SPRINT (see Figure 11.1) are in the center of a training loop, rowing on the mechanical platform, which is the main interface. Performance is captured by a set of sensors and analyzed via software in order to feed back information to the users, thus closing the loop. SPRINT is composed of four components—mechanics,

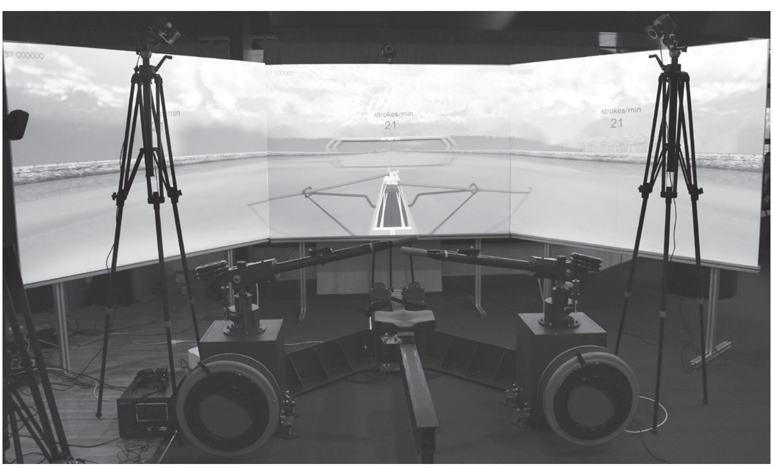

FIGURE 11.1 *(See color insert.)* The SPRINT system.

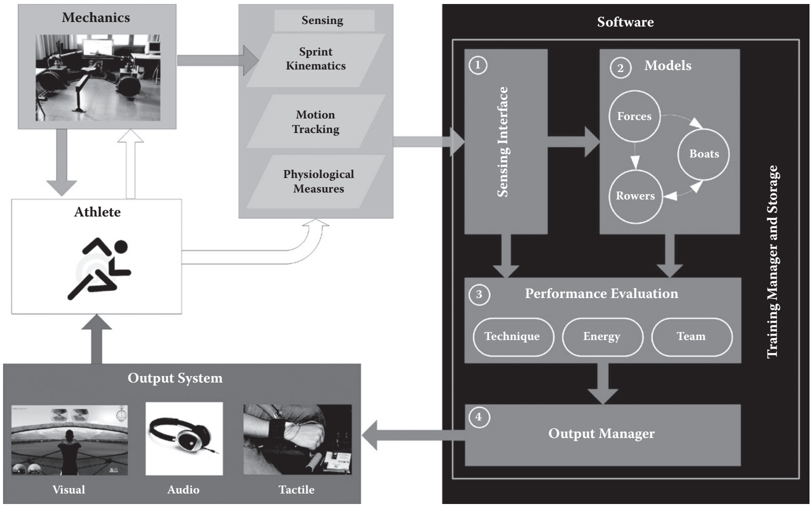

FIGURE 11.2 *(See color insert.)* Architecture of the SPRINT rowing system. (From Emanuele Ruffaldi and Alessandro Filippeschi, Preliminary evaluation of timing training accelerator for the SPRINT rowing system. *EDP Sciences*, 2011.)

AU: Ruffaldi and Filippeschi 2011 is not in Refs—please add and format correctly with ref info as needed (page, vol., etc).

sensing, software, and multimodal output—which are described below. Figure 11.2 shows the overall architecture and the various components.

The *mechanical system* is composed of a steady rail and two steady boxes. The rail bears a sliding seat and a foot-stretcher. Height of the rail and position of the foot-stretcher can be adjusted. The boxes support oars and force rendering devices. They can be used together or one at a time, allowing sculling and sweep rowing, with possible regulation of geometry and load. Force rendering is provided by a fan mounted on a flywheel, making load dependent on the oar's angular speed, angular acceleration, and airflow blown by the fan (but not handle height).

The *sensing system* varies according to the training purpose. The simplest configuration is composed of six encoders measuring oars' angles and fan angular speed, plus an infrared sensor capturing seat displacement. This basic configuration can be enhanced with motion tracking systems (e.g., Vicon by Oxford Metrics, United Kingdom) or physiological recorders (e.g., Cosmed K4 and Polar belt), if necessary.

The *software system*, developed in Simulink (Mathworks, Natick, Massachusetts), is the core of the SPRINT platform. It is composed of four levels. A first level contains the interfaces with the sensing devices. The second level implements the physical models for force rendering, athlete, and boat-oars-rower systems. These models provide an estimation of user performance in terms of boat motion, rowers' internal forces, torques, inertia, and energy. The third level indicates performance. According to the raw data and the physical models, performance indices are computed for three skill elements: rowing technique, energy management, and team coordination. The fourth level includes the output manager, selecting the information displayed to the user through the SPRINT modalities. Visual, audio, and tactile outputs are decided according to the feedback selected for training. At this level, performance is mapped to feedback triggering, for example, switching the color of an element of the virtual environment, or delivering or not a feedback. In parallel to these four levels the SPRINT software organizes the various training sessions and ensures data storage. The user is able to set, automatically from a template or manually, the various training variables such as workout, rest times, distance to be covered, and feedbacks to be given. The relevant variables recorded in each training session are stored in a SQL database structure managing HDF5 datasets (see also Chapter 10).

The output system is composed of an immersive graphical environment, vibrotactile effectors, and an audio engine. The graphical component provides the scenario where the training takes place. The scenario is composed of a channel in which one or several boats move propelled by virtual rowers, which may be displayed with their movements precisely controlled. Training information in the graphic scenario may be conveyed by elements of the scenario (see the coordination experiment below), by symbolic elements immersed in the scenario (such as the arrow used in the energy management experiment below), or by elements not belonging to the scenario (such as the number superimposed on the scenario indicating the current pace). Vibrotactile displays are composed of vibrating motors housed in wristbands or belts worn by the user, delivering tactile feedback about performance, timing, or path motion (Ruffaldi et al., 2009, see also Chapter 8). Speakers provide audio information, delivered in a feedback form, or used to increase the scenario realism. Binaural recording of outdoor rowing allowed current user performance to be synchronized with the typical sounds of outdoor rowing.

Orchestration

A key characteristic of the output system is a messaging mechanism controlling most of the elements in the environment. The graphical application is a player of commands that can be used to display real-time performance, to deliver various stimuli for training purposes, or to playback from previous training sessions. Some commands allow reconfiguring the environment, specifying, for example, the number of boats and rowers. Others provide real-time updates of the environment. Some commands cover general aspects of the virtual environment, such as virtual time or camera position, while others control the placement and visibility of virtual boats and avatars. More specific commands display information related to a given training protocol.

Training Model

Training tasks were selected according to task analysis, and accelerators—combinations of variables to be tracked, feedback, and protocols (see Chapter 2)—were selected in three steps. The taxonomy of VE training feedbacks and accelerators for sport training in general and for rowing in particular can be found in Ruffaldi et al. (2011). First, variables to be tracked were selected. Then selected feedbacks were chosen according to the literature on motor skills learning and training in VE (see Chapter 3). The accelerators included in this work are (1) a multimodal audio/vibro-tactile feedback about the rowing technique; (2) visual information in the form of an opponent avatar, about the management of energy stock during the race; and (3) visual information about between-rower synchronization during team rowing. All information was presented on line modulated in real time by the rowing action during training protocols involving pre- and post-tests, learning and retention sessions. The results are presented below.

Protocol Design

Training protocols are structured according to a time hierarchy: A protocol is composed of days, sessions, and blocks, whose arrangement depends on the task, the selected feedback, fitness, and expertise of the rower. Task and fitness limit upper and lower bounds of blocks duration, rest time between blocks, and number of blocks per session (e.g., race simulation). For example, intermediate rowers may require longer training sessions than novices to acquire a new technique because they may have to annihilate their representation of the task or their already stable sensorimotor repertoire (e.g., Faugloire et al., 2009). However, long protocols can be carried out only by fit rowers; hence the final protocol should take into account both fitness and expertise. In the following sections, we report the results of three experiments recently performed on the SPRINT system, designed to evaluate the efficiency of the platform in the training of technique optimization, energy management, and team rowing.

LEARNING TECHNIQUE OPTIMIZATION

Objective

Technique optimization training aims at providing novice rowers with an overall correct representation of the rowing cycle, allowing them to start rowing appropriately. Technique evaluation uses expert performances that were first recorded on the SPRINT platform. The obtained dataset was used to develop digital models of the technique features characterizing both correct rowing and technique faults. Some of these features were taken from literature (Nolte, 2005) and mapped on the variables available in SPRINT (e.g., deep blade entry maps on oars angles). Other features (e.g., timing of body limbs) were obtained from the recorded data. The feedback selection was done according to the training model.

Evaluation

The evaluation followed a pretest, training, post-test, and retention design. The goal for the participants was to synchronize motion onsets of their legs, back, and arms during the drive phase. The information exchange relied on audio guidance, vibrotactile feedback, and delayed offline knowledge of results (KR). The participants were eight naïve rowers screened for handedness and general health. They were asked to row following the imposed timing. The timing pattern was captured from expert performances but with two simplifications: the load was removed in the first training part and the threshold on arm motion onset was loosened in order to ease the participant to fix at least arm motion. Participants were divided into two groups (four participants in each group) with or without vibrotactile feedback. The audio cue, available for all participants, consisted of two signals triggered at specified moments in time. These signals represented instants at which participants were instructed to start swinging their backs and bending their arms, respectively. The vibrotactile feedback was provided by two vibrating motors arrays: one housed in a wristband and the other embedded in a belt worn on the midriff. Vibrations on the wrist or on the back were triggered when the onset of arm or back motion exceeded a set threshold. The delay between vibration and audio allowed the participants to establish whether their movements were synchronized with the audio tone. All participants received a delayed KR about the missed cycles ratio over the total number of strokes after each trial.

Procedure: The experiment was carried out in three consecutive days: two days of training and a third day of test. The last day included a retention test, which was carried out with full load.

The onset times of arms and back motions were used as metrics compared to the trained reference. The back and arm timing errors e_a and e_b were computed for every stroke and made relative to the reference.

Results: Figure 11.3 shows the error for each pre, post, and retention session in the full-load condition after having averaged the error per session for compensating the different lengths in number of strokes. Both VIB-KR

AU: Spell out VIB-KR

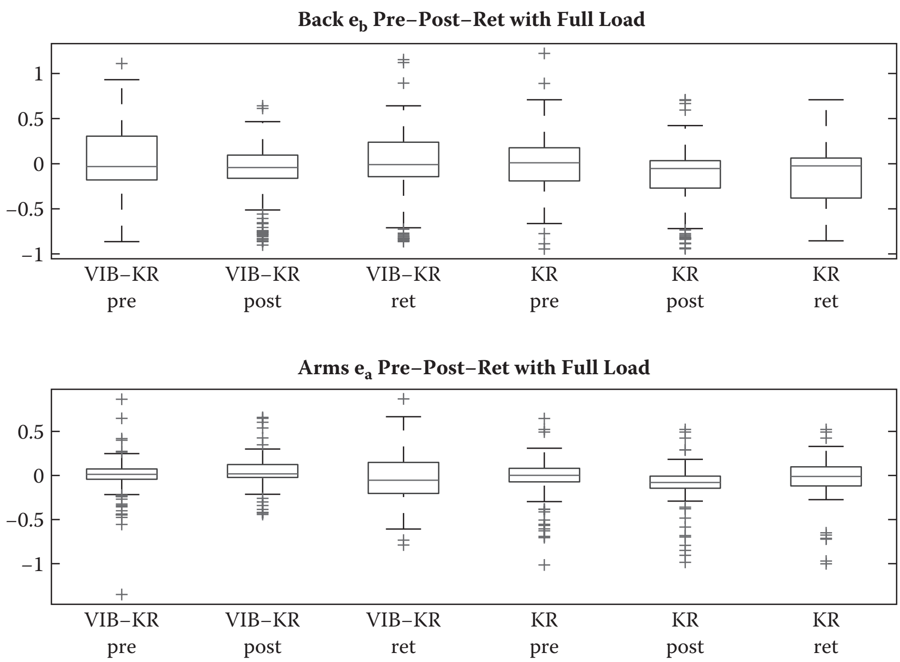

FIGURE 11.3 Statistics of the technique optimization experiment focused on the full load condition. In the top part the back timing error is presented for three sessions—pre, post, and retention—separated by the two groups, the experimental (VIB-KR) and the control (VIB-KR). In the top part the arm timing error is presented.

and KR participants generally reduced their error of back and arms. The arm error was generally lower than that of the back. The vibrotactile feedback did not add any benefit when coupled with audio guidance and KR. Investigating the progress of subjects during training, they were not able to avoid errors most of the time, and they tried either to focus on one limb or to keep the right time lapse between limbs onset. These results indicate that stimulating the training of a multilimb activation pattern is challenging because it is perceived as a multigoal task, and, although the feedback scheme is promising, it has to be supported by a more focused protocol.

ACCELERATING THE MANAGEMENT OF ENERGETIC RESOURCES

Objective

Olympic rowing events are conducted over a 2000 m race. Individual races on this distance last between 320 and 500 s. Rowing performance is constrained by several factors that should be taken into account during training, such as the rower's fitness status, the specific technique, as well as intra- and interindividual coordination. In the study described below, we focused on one other important factor, the ability of rowers to manage their energy stock during a 2000 m race. Garland (2005) reported that elite rowers adopt a particular pacing strategy. Their velocity corresponds to a fast-start profile, with the first 500 m performed at 103.3% of the average whole race speed, and with the subsequent sectors rowed at 99%, 98.3%, and 99.7% of the average speed, respectively.

Here we used virtual reality in order to determine if novice rowers were able to acquire and maintain this energy management skill during a 2000 m race, with positive consequences for rowing performance. We used an avatar on a screen located in front of the rowers to impose boat speed, in intrinsic units (i.e., in proportion of the actual capacity of the participants). We expected after training a better management of energy consumption for the avatar group compared to the control group. The protocol (Figure 11.4) was performed on the lightweight rowing platform based on the Concept2 indoor rowing machine by two groups of novice males. After a pretest both groups performed a 2000 m race twice a week, for a total of eight learning sessions. One group followed a classic indoor rowing training. The other group benefited from an energy-management information represented by an avatar boat visible on a large screen located in front of the participants. Participants (of the avatar group) were instructed to track the virtual boat, whose velocity was previously calibrated to follow the appropriate to-be-learned velocity profile along the 2000 m race. The virtual opponent was gradually removed at the end of the race along the 4 weeks of learning. After the 4 weeks training period, both groups achieved a post-test to evaluate the effect of the velocity profile accelerator. A retention test was performed 30 days later in order to evaluate the durability of learning.

A general analysis of variance (ANOVA) revealed a significant decrease in race duration between the pre- and post-tests. It also revealed an interaction effect

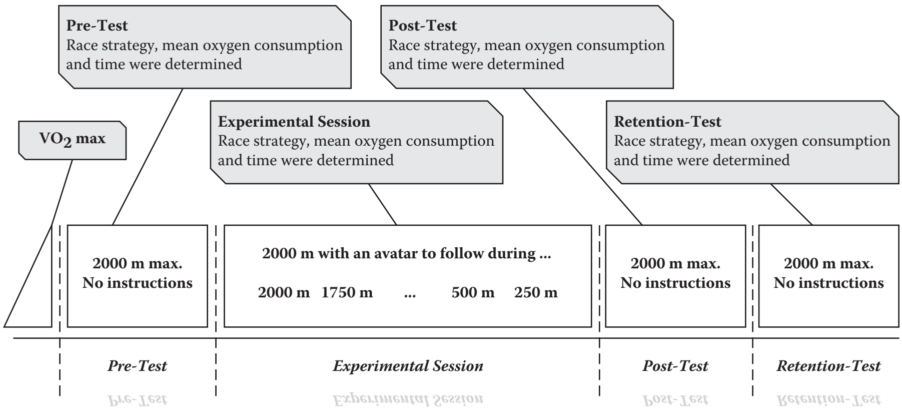

FIGURE 11.4 The energy management protocol.

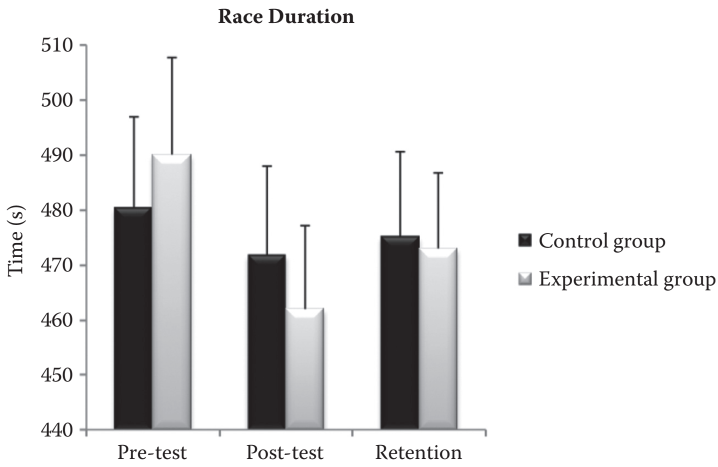

FIGURE 11.5 Race duration comparing avatar group (black) and control group (gray) for pre-, post-, and retention tests.

between groups and tests showing that the pre-post and the preretention difference concerned only the avatar group. Figure 11.5 summarizes graphically these results.

In addition we observed that the avatar group learned the expert profile and maintained it during the retention test (Figure 11.6). Concerning the oxygen consumption, we found an increase in VO_2 for the avatar group, which can be correlated with the fact that participants increased their rowing frequency compared to the control group. The control group did not reveal any differences between pre, post, and retention tests.

Our results indicate that virtual reality can be used to accelerate the learning of energy-related skills in a relatively short period of time (4 to 5 weeks). This learning can lead to a better performance in terms of race duration. These results open new

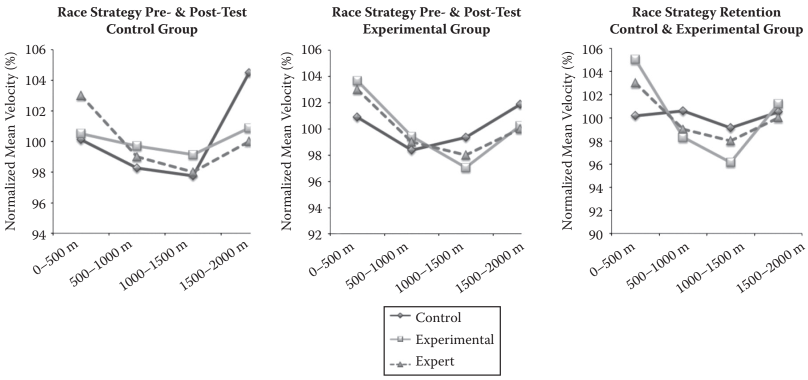

FIGURE 11.6 Race pace profiles comparing pretest (straight black line), post-test (gray line), and the expert profile (dashed black line) for the control group (a) and the avatar group (b). Race pace profiles comparing control-group (straight black line), experimental group (grey line), and the expert profiles (dashed black line) in the retention.

issues concerning the transfer of pacing strategy to other sports including races of similar duration (6 to 8 minutes) such as running or sprint cycling, for instance.

LEARNING TEAM COORDINATION USING A VIRTUAL PARTNER

Objective

As mentioned above, performance in rowing depends on several factors such as the fitness status of the rowers, their energy management, and their technique (Baudouin and Hawkins, 2002). However, individual skills of rowers are often equivalent, and the difference in performance between two teams strongly depends on the ability of the athletes to row together in a highly synchronized way during the race (Hill, 2002). Although the synchronization between the movements of rowers is a significant factor of performance, the learning of team rowing coordination is limited in classical training situations. It is difficult for the coach to have an accurate estimation of the coordination of the team and to give efficient feedback to the trainees. Even if more accurate estimation of the synchronization is possible with video analyses, it does not allow the delivery of feedback in real time. Here we report a recent study (Varlet et al., submitted) in which we used virtual reality and real-time human movement capture technologies in order to accelerate the learning of team rowing coordination in VR (i.e., Filippeschi et al., 2009). We expected better team rowing coordination after training in VR, which would be stronger for the group that benefited from the real-time feedback.Design

Sixteen participants have been evaluated on the lightweight platform composed of a Concept2 indoor rowing machine located in front of a large screen (see Figure 11.7). The movements of the handle and the seat of the rowing machine were captured at a sampling rate of 100 Hz by using infrared marker based Vicon MX13 cameras. The participants performed pre-, post-, and retention tests in which they had to row as

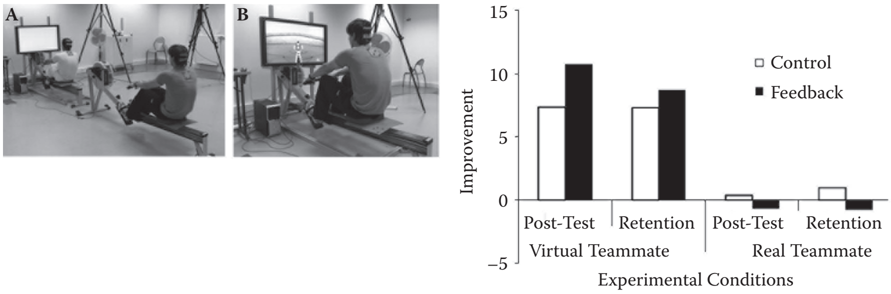

FIGURE 11.7 *(See color insert.)* Left. Experimental setup. (a) Coordination with real teammate. (b) Coordination with virtual teammate. Right. Improvement compared to the pretest of the synchronization for control (white) and feedback (black) groups in the different experimental conditions.

synchronized as possible with a virtual teammate displayed on a monitor in front of them, and in a transfer task with a real teammate (see Figure 11.7). After the pretest, participants performed four learning sessions (one per day with a day break halfway) before performing the post- and retention tests, 1 and 4 days after the last learning session, respectively. The duration of the trials was 90 s, and we used the frequencies of 18, 24, and 30 strokes/min. Participants performed two trials of each frequency for pre-, post-, and retention tests, and four trials for each frequency for the learning sessions. All trials were counterbalanced.

Two groups of eight participants (mean age of 21.4 years) were composed. During the learning sessions, they were instructed to synchronize their movements with the virtual rower while having a real-time visual feedback giving either information about the coordination (Feedback group) or no information at all (Control group). For the Feedback group, we computed in real time the degree of synchronization of the trainee and used it to change continuously the color of the virtual teammate between red (not synchronized) and green (well synchronized). To measure the synchronization between the movements of the participants and their teammate (real or virtual), we computed the cross-spectral coherence giving an index of synchronization between 0 and 1 with 1 indicating a perfect synchronization and 0 indicating no synchronization (Schmidt and O'Brien, 1997). We averaged the synchronization measures at the level of the seat and the handle, and we computed then the percentage of improvement in post- and retention tests compared to pretests. The results are presented in Figure 11.7.

Evaluation

A $2 \times 2 \times 2 \times 3$ repeated-measures ANOVA with variables of Group (Control and Feedback), Teammate (Virtual and Real), Test (Post- and Retention tests), and Frequency (18, 24, and 30 strokes/min) performed on the improvement percentages of participants yielded a significant main effect of Teammate (F (1,7) = 57.05, $p < .05$) and a significant interaction between Teammate and Group (F (1,7) = 7.21,

$p < .05$). As depicted in Figure 11.7, these results demonstrate that participants of the Control and Feedback groups produced better performance in post- and retention tests compared to the pretests while synchronizing with the virtual teammate, and that this improvement was stronger for the Feedback group that had real-time information about the coordination during learning sessions.

As expected, these results show that the learning of team rowing coordination is possible using VR technology and that the use of feedback giving information about the synchrony allows accelerating the learning in line with previous research on daily postural activity (e.g., Faugloire et al., 2005). However, our results did not reveal a significant influence of the learning sessions in VR on the participants' performance in the transfer task where they had to synchronize with a real teammate. Generally, our study showed the interest of VR and motion capture technologies for learning coordination in rowing, and encourages further exploration in order to develop learning protocols in rowing and other sport activities.

PERSPECTIVES AND CONCLUSIONS

The three training scenarios described above show several opportunities for research in the domain of VR and sport. First, at a methodological level, it is clear that is possible to integrate and customize an expert performance profile inside training protocols, allowing the training of complex perceptuomotor elements such as the combination of activation patterns found in rowing. These profiles, as shown by the three accelerators, emerge at multiple levels of rowing behavior and cover different aspects of the task, from single stroke to higher-level strategy. The key element behind the profile identification, which has not been discussed in depth here, is the construction of a digital representation of the rowing skill that allows characterizing expertise and performance. This representation is a combination of existing knowledge and machine learning–based analyses that provide a working mechanism for scoring performance and controlling virtual participants.

The second fundamental aspect is the identification of training feedback and their combination with training protocols capable of maximizing the real-time analysis and synthesis capabilities of VR technologies. The embodiment of training in the form of a virtual human is the element that characterizes the accelerators presented above. In two cases the virtual human conveys the training feedback in the form of a partner, in one case for keeping a certain rowing distance, in the other for team synchronization. In both cases the virtual human is not an opponent that has to be fought, although this could be an added interest for increasing motivation and entertainment.

Two related aspects could be considered as sources for future investigation, feedback adaptation and protocol duration. The intensity and type of feedback provided to the user were fixed or partially progressive in our case, allowing for reduction of dependency. Although the results are encouraging, the adoption of an adaptive scheme of feedback would possibly increase the training effect, adapting the level of difficulty during the protocol. As a conclusion, we think that the approach presented in this work paves the way to more effective training strategies and experimental designs not only in the domain of rowing training but in VR sport training in general.

ACKNOWLEDGMENTS

The work presented in this chapter was supported by the SKILLS integrated Project (IST-FP6 #035005, http://www.skills-ip.eu) funded by the European Commission.

REFERENCES

Aoki, H., Oman, C.M., and Natapoff, A. 2007. Virtual-reality-based 3D navigation training for emergency egress from spacecraft. *Aerospace Medical Association* 78: 774–783.

Bailenson, J., Patel, K., Nielsen, A., Bajscy, R., Jung, S.-H., and Kurillo, G. 2008. The effect of interactivity on learning physical actions in virtual reality. *Media Psychology* 11: 354–376.

Baudouin, A., and Hawkins, D. 2002. A biomechanical review of factors affecting rowing performance. *British Journal of Sports Medicine* 36: 396–402.

Bideau, B., Kulpa, R., Ménardais, S., Fradet, L., Multon, F., Delamarche, P., et al. 2003. Real handball goalkeeper vs. virtual handball thrower. *Presence: Teleoperators and Virtual Environments* 12: 411–421.

Faugloire, E., Bardy, B.G., Merhi, O., and Stoffregen, T.A. 2005. Exploring coordination dynamics of the postural system with real-time visual feedback. *Neuroscience Letters* 374: 136–141.

AU: Cite in txt Faugloire et al. 2006

Faugloire, E., Bardy, B.G., and Stoffregen, T.A. 2006. The dynamics of learning new postural patterns. Influence on pre-existing spontaneous behaviors. *Journal of Motor Behavior* 38: 299–312.

Filippeschi, A., Ruffaldi, E., Frisoli, A., Avizzano, C.A., Varlet, M., Marin, L., Lagarde, J., Bardy, B.G., and Bergamasco, M. 2009. Dynamic models of team rowing for a virtual environment rowing training system. *International Journal of Virtual Reality* 4: 19–26.

Garland, S. 2005. An analysis of the pacing strategy adopted by elite competitors in 2000 m rowing. *British Medical Journal* 39: 39–42.

Hill, H. 2002. Dynamics of coordination within elite rowing crews: Evidence from force pattern analysis. *Journal of Sports Sciences* 20: 101–117.

Iskandar, P., Hanum, Y., Gilbert, L., and Wills, G. 2008. Reducing latency when using Virtual Reality for teaching in sport. *International Symposium on Information Technology*.

AU: Iskandar et al. 2008: Provide more info

Multon, F., Kulpa, R., and Bideau, B. 2011. Special issue: Virtual reality and sports guest editors' introduction. *Presence: Teleoperators and Virtual Environments*, 20(1).

Nolte, V. 2005. *Rowing Faster*. Champaign, IL: Human Kinetics.

Ruffaldi, E., Filippeschi A., Frisoli, A., Sandoval, O., Avizzano, C.A., and Bergamasco, M. 2009. Vibrotactile perception assessment for a rowing training system. *Proceedings of the Third IEEE Joint Conference on Haptics 2009*, Salt Lake City, UT.

AU: Ruffaldi et al. 2009: Provide ed(s), pg #s

Ruffaldi, E., Filippeschi, A., Avizzano, C.A., Bardy, B.G., Gopher, D., and Bergamasco, M. 2011. Feedback, affordances and accelerators for training sports in virtual environments. *Presence: Teleoperators and Virtual Environments* 20(1): 33–46.

Schmidt, R.C., and O'Brien, B. 1997. Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychology* 9: 189–206.

Varlet, M., Filippeschi, A., Ben-sadoun, G., Ratto, M., Marin, L., Ruffaldi, E., and Bardy, B.G. Learning team rowing coordination using virtual reality. *SPRINT.* Manuscript submitted for publication.

Vignais, N., Kulpa, R., Craig, C., and Bideau, B. 2010. Virtual thrower vs. real goalkeeper: Influence of different visual conditions on performance. *Presence: Teleoperators and Virtual Environments* 19: 281–290.

Wulf, G., and Shea, C.H. 2002. Principles derived from the study of simple skills do not generalize to complex skills learning. *Psychomonic Bulletin and Review* 9(2): 185–211.

Zitzewitz, J. von, Wolf, P., Novakovic, V., Wellner, M., Rauter, G., Brunschweiler, A., et al. 2008. A real-time rowing simulator with multi-modal feedback. *Sports Technology* 1: 257–266.