Daniel R. Mestre*
Christophe Maïano
Institute of Movement Sciences
CNRS and Université de la
Méditerranée
Marseille, France

Virginie Dagonneau
Laboratoire Exploitation, Perception,
Simulateurs, et Simulations
INRETS-LCPC
Paris, France

Charles-Symphorien Mercier
Centre AJO® Les Oiseaux
SSR Pédiatrique Obésité
Sanary-sur-Mer, France

Does Virtual Reality Enhance Exercise Performance, Enjoyment, and Dissociation? An Exploratory Study on a Stationary Bike Apparatus

Abstract

The present study aimed at testing the general assumption that virtual reality can enhance the experience of exercising. More specifically, we tested the effects of sensory input (music and video feedback) during physical training on performance, enjoyment, and attentional focus by means of a computerized ergometer coupled with VR software. Twelve university students participated in the study. The experimental procedure consisted in a $2 \times 3 \times 4$ mixed design, with two types of feedback (video feedback vs. video feedback and music), three course phases (e.g., flat, uphill, and downhill) and four sessions (task repetition). The virtual feedback was a video film of the course that participants had to complete. Video display speed was proportional to the participant's pedaling speed. Force feedback, applied to the real bicycle wheel, was proportional to the instantaneous course slope. The results showed a positive effect of task repetition on participants' performance only when video feedback was associated with listening to music. In an attempt to objectively assess attentional focus, we analyzed participants' gaze orientation. Gaze analysis showed a reduction in the time spent gazing at video feedback across sessions. Associating video feedback with freely chosen music led to a differential use of video feedback as a function of exercise intensity. Finally, sensory stimulation appeared to have a dissociative role on participants' attentional focus during exercise, but adding music listening to video feedback appears to be necessary to maintain (long term) the participants' commitment to the task. The results are discussed in terms of the functional status of sensory stimulation during exercise, and its interactions with exercise intensity, participants' performance, and attentional focus. They also suggest that gaze analysis is one promising way to access attention allocation and its relationships with performance.

1 Introduction

Recent advances in technology have facilitated the development of virtual reality (VR) indoor stationary exercise bike equipment (Nigg, 2003). These VR units create an interactive virtual environment involving a combination of auditory and visual stimulation in which the users exercise on a stationary bike. The bicycle itself is equipped with a variable resistance device that modulates exercise

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*Correspondence to daniel.mestre@univmed.fr.

intensity as a function of the virtual environment. With this equipment, the software receives data from the participant's performance and continuously controls the sensory and strength feedback sent to the participant as a function of his or her progression into the virtual environment.

The general objective behind the introduction of such VR equipment in the general population (in a fitness context) was to increase the user's involvement and adherence (Dishman, 1993). By using an exercise program that diverts attention from unpleasant bodily sensations (i.e., muscular pain, increased breathing) and thus delaying the onset of boredom and fatigue (Annesi & Mazas, 1997; Annesi, 2001), it is indeed possible to incite higher participation. According to Annesi and Mazas (1997), the shift from an internal to an external attentional focus may be attributed to VR external sensory stimulation (i.e., visual and/or auditory). Thus, VR effects on exercise may be related to two broad categories of attentional focus: association refers to an internal attentional focus, in which participants focus their attention on internal sensations, whereas dissociation refers to an external attentional focus, in which participants' attention is diverted from internal sensations, toward external distracting stimulation (Masters & Ogles, 1998; Morgan & Pollock, 1977; Hutchinson & Tenenbaum, 2007). However, until recently, very few studies examined whether VR stationary exercise bike equipment truly promotes a dissociation attentional focus and enhances enjoyment of the experience. Indeed, few studies have directly tested the effect of a VR setting on affective states and/or performance during indoor cycling (Annesi & Mazas, 1997; Chuang et al., 2003; Huang, Tsai, Sung, Lin, & Chuang, 2008; IJsselsteijn, De Kort, Westerink, De Jaggerand, & Bonants, 2006; Mac Rae, Miller-Perrinand, & Tinberg, 2003; Plante, Aldridge, Ogden, & Hanelin, 2003; Plante, Frazier, et al., 2003).

Annesi and Mazas (1997) tested the effect of a 14-week VR exercise bicycle program in a fitness center on adherence and exercise-induced feeling states among 45 adults, aged between 20 and 60 years. The study used the Tectrix VR bicycle, a recumbent bike connected to video-game-like VR software, with a computer screen placed in front of the user. The results exhibited a positive and significant effect of VR on adherence and attendance, when compared to classical upright or recumbent exercise bikes. However, they failed to demonstrate any significant difference between VR-assisted equipment and standard exercise bicycle programs on affective states.

Plante, Aldridge, et al. (2003) investigated whether VR technology enhances the psychological benefits of aerobic exercise among 88 adults. Participants were randomly assigned to one of three 30-min conditions: (i) bicycling at a moderate intensity (i.e., 60–70% maximum heart rate) on a stationary bike, (ii) playing a VR computer bicycle game, or (iii) an interactive VR bicycle experience on a computer while exercising on a stationary bike at moderate intensity. The results revealed that VR coupled with exercise enhanced enjoyment and energy while reducing tiredness. In contrast, VR without exercise increased participants' tension and tiredness, meanwhile decreasing their energy level. In similar conditions, Plante, Frazier, et al. (2003) also reported long-lasting positive psychological effects of VR added to exercise experiment.

Mac Rae et al. (2003) examined whether trained and untrained women's physiological (heart rate, maximal oxygen consumption, etc.), performance (speed, distance, etc.) and psychological (mood, feeling, satisfaction, etc.) characteristics were altered when they were exposed to interactive video feedback and music, compared to music-only feedback. The results showed that the average speed and distance cycled were significantly improved in the interactive video feedback and music condition compared to the music condition, when participants were considered to be untrained. Nevertheless, no significant group differences were observed for psychological effects.

IJsselsteijn and colleagues (2006) investigated the effects of immersion and coaching by a virtual agent on intrinsic motivation and the sense of presence for participants cycling on a stationary home exercise bike. In this study, two levels of immersion (high vs. low, i.e., egocentric vs. allocentric view) and two levels of coaching (with vs. without, the coach being a virtual agent) were tested. The results confirmed a positive and significant effect of immersion on average speed, in favor of the high immersion condition, on four dimensions of intrinsic motivation (i.e., interest/enjoyment, perceived competence, value/usefulness, and perceived control) and on three dimensions of presence (i.e., spatial presence, engagement, and ecological validity).

From these studies, it is not clear whether VR exercise systems truly enhance mood states, and more specifically, enjoyment. Further, the relationships between psychological and performance effects of VR are not straightforward. Moreover, recent studies failed to test multisession training, in order to test for a possible novelty effect on participants' behavior. Finally, the hypothesis that VR exercise promotes an external attentional focus was never directly tested in conjunction with the possible enhancement of enjoyment.

Considering that various sensory stimuli can be provided by VR systems, it is conceivable that the internal/external attentional focus balance will depend on the virtual feedback informational format as well as on exercise intensity (Russell & Weeks, 1994). Additionally, Mac Rae et al.'s (2003) study notably suggests that the combination of VR and music is decisive in inducing positive effects on participants' performance. Therefore, as suggested by Karageorghis and Terry (1997), one might hypothesize that music induces a dissociative attentional focus. However, Mac Rae et al. (2003) did not test this aspect. Finally, few studies have directly tested VR effects on exercise performance. Indeed, in a recent paper Huang et al. (2008) report that VR feedback actually enables anaerobic exercise for longer duration by reducing perceived exertion (see also Chuang et al., 2003). However, these two studies were conducted in a rehabilitation (poststroke) context that may not be easily generalized to nonpathologic populations. It seemed thus appropriate to design a study, aiming at testing the relationship between affective states and performance, as a function of information format in a VR setting, among a group of healthy participants.

To achieve this objective, we designed a controlled experimental study in which two conditions of sensory feedback were tested in a bicycling task performed on an ergometer. In the first condition, we tested the effect of VR feedback, coupling the participant's pedaling speed to the display speed of a prerecorded video of a real race. In a second condition, participants could listen to music while watching the video. This latter condition was expected to further promote an external attentional style. Questionnaires were used to evaluate participants' commitment, attentional focus, and enjoyment. In addition, we tried to objectively assess attentional focus by analyzing participants' gaze orientation. Indeed, gaze orientation appears to be an instantaneous behavioral indicator of cognitive processing and attentional allocation in an environmental scene (Masson & Mestre, 1998; Henderson, 2003). Without going into detail (see Duchowski, 2007, for a detailed introduction to eye tracking methodology), we can simply note that there are a number of available techniques for measuring gaze location in a 3D environment. Some of these techniques are fairly constraining in that they restrain head movement (such as the coil system or the Purkinje system) but thus allow one to obtain maximal temporal and spatial resolution. Some are poor in resolution and sensitive to muscular noise, such as electro-oculography, which uses electrodes placed around the eyes. Nowadays, the most common technique is video-based (with infrared cameras filming the eye). Under certain circumstances, it is possible to measure gaze movements under the condition where the head is free to move. However, none of the commonly available systems are easy to use in natural conditions, and especially not when a participant is exercising. Therefore, in this exploratory study, we decided to simply film the participant's face as a first approximation to gaze analysis. Finally, performance analysis was carried out to test for the behavioral effects of virtual feedback and their relationship with enjoyment, commitment, and attentional focus.

2 Methods

2.1 Participants

Twelve university students (six males, six females), aged between 21 and 25 years ($M = 22.92$, $SD = 1.44$) participated. Participants were selected based on the following criteria: (i) they were between 18 and 30 years of age, (ii) they could be a man or a woman; (iii) they did not present any medical contraindication for athletic participation, according to responses given on the physical activity readiness questionnaire (PAR-Q; Thomas, Reading, & Shephard, 1992); (iv) they were at least moderately physically active ($\geq$600 metabolic equivalent-min/wk; this measure quantified the average amount of time of physical activity per week) according to the categorical score obtained on the international physical activity questionnaire (IPAQ; Craig et al., 2003); (v) they were at normal weight according to international body mass index (BMI) standard (from 18.5 to 24.9 kg/m^2; see Després, Lemieux, & Prud'homme, 2001); (vi) they had a waist-to-hip ratio in the normal range ($<$0.85 for a women and $<$0.95 for a men; see Després et al., 2001); and (vii) they did not practice cycling, either recreationally or competitively. These criteria were chosen to obtain a sample of noncycling, healthy, and physically active young adults. Indeed, we tried to avoid possible interference of health condition (e.g., obesity), sedentary behavior and cycling competence with the experimental protocol. These measures were obtained during a preliminary inclusion phase described below.

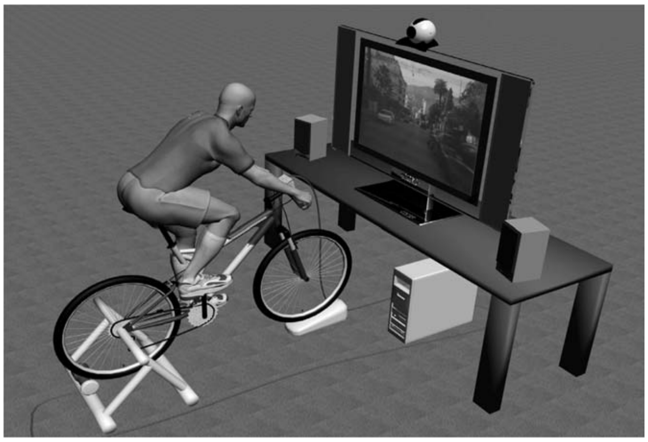

Figure 1. *Experimental setup. The participant was asked to pedal on a stationary bike connected to a computer running VR software via a device (see Figure 2) controlling resistance proportional to course topology (see Figure 3) and measuring his or her pedaling speed. Participants could watch a prerecorded video of the course on a display terminal in front of them. The video speed was proportional to pedaling speed. A webcam was used to evaluate gaze behavior.*

2.2 Inclusion Phase

The inclusion phase was conducted over two sessions separated by a 1-week interval in the presence of a physician (the fourth author). During the first session, all participants completed a French version of the PAR-Q (Thomas et al., 1992) and of the IPAQ (Craig et al., 2003) to determine health condition and physical activity level, respectively. Additionally, all participants were weighed on a digital balance scale and measured for height (without shoes and in sportswear) as well as waist using a vertical ruler and a tape measure, respectively. Then, the body mass index (BMI) was estimated based on the following formula: BMI (kg/m^2) = weight (kg)/height^2 (m).

During the second session, all participants were interviewed by the same physician, who assessed them on the physical activity readiness medical examination PARQ (Thomas et al., 1992). Finally, the predicted peak oxygen consumption ($V_{O_{2peak}}$) was measured with the Luc-Léger 20 m shuttle run test (for more details on the test, see Léger & Lambert, 1982). The following formula was used:

$$V_{O_{2\max}} = 31.025 + 3.238 \times \text{speed(km/hr)} - 3.248 \times \text{age(years)} + 0.1536 \times \text{age} \times \text{speed}$$

where speed corresponds to the speed observed at the last level tested.

2.3 Experimental Design

2.3.1 Cycling Apparatus. The experimental setup consisted of a stationary bike installed in front of a computer screen (see Figure 1) and connected to a computer on which the RealAxiom (Elite®) VR software was running and displayed a real prerecorded video film of a portion of the Milan-San Remo cycle race in Italy. The film was recorded onboard a car equipped with a video camera and appropriate electronic equipment, measuring distances and elevations on the road. The film was later digitized, incorporating distance and elevation data for use in the Realaxiom software (B. Deveza, personal communication).

During exercise, the software controlled the effort feedback sent to participants through a pad fixed on the rear wheel (see Figure 2). This effort feedback was expressed through an electromagnetic brake whose

Figure 2. *Electromagnetic brake and sensor placed on the bike's rear tire.*

resistance strength was proportional to the instantaneous virtual course slope. The software also recorded participants' pedaling speed, via an optical detector placed on the same device (see Figure 2). Finally, the software used the participant's pedaling speed to control the video display speed of the prerecorded course (visual feedback) on the screen in front of the participant (see Figure 1). Thus, video speed was proportional to the participant's pedaling speed.

2.3.2 Procedure. Participants were pseudorandomly assigned to one of two experimental groups, according to gender, physical activity level, and predicted peak oxygen consumption. Two intergroup experimental conditions were tested. The first group was assigned to the video condition, consisting of the display of a prerecorded real course on a computer monitor. The display rate was proportional to the participant's pedaling rate. The second group was assigned to the video + music condition. In addition to being exposed to the video stimulation, participants wore earphones while exercising in order to listen to their favorite music during exercise.

The descriptive statistics for each group are presented in Table 1. A one way univariate analysis of variance (ANOVA) failed to find any significant differences between the groups at the beginning of the experimentation for age, $F(1,10) = 0.04$, $p = .85$; BMI, $F(1,10) = 1.42$, $p = .26$; waist/hips ratio, $F(1,10) = 0.59$, $p = .46$; physical activity level, $F(1,10) = 0.01$, $p = .93$; or $V_{O_{2peak}}$, $F(1,10) = 0.08$, $p = .79$].

Each participant completed four experimental sessions, with a one-week interval between sessions. The first session was performed in the absence of sensory stimulation (video or music), to define a common baseline for both experimental groups. The subsequent sessions (T1, T2, and T3) were performed on the same course with video feedback. Participants were asked to complete a course at their chosen speed, but without modifying gear ratio or gearwheel. Participants received no feedback concerning exercise duration or remaining distance to the finish line, which was figured on the display screen. The exercise consisted of completing a 7.5 km long course, with a total change in altitude of 78 m. This course, illustrated in Figure 3, was composed of three phases: (i) flat (from 0 to 3 km), (ii) uphill (from 3.1 to 4.8 km), and (iii) downhill (from 4.81 to 7.5 km).

2.3.3 Behavioral Measures

2.3.3.1 Performance. Instantaneous heart rate (expressed in bpm), instantaneous power (in watts), and traveled distance were recorded by the VR software every second as a function of exercise time. Heart rate was measured using a Polar electro S410 heart rate monitor connected to the VR software. Power was computed by the VR software. Offline analysis consisted of calculating, for each participant and each session, the average heart rate, average power, and duration for each course phase (flat, uphill, and downhill).

2.3.3.2 Gaze Behavior. Gaze was measured and recorded during exercise, relying on participant's face recorded by a video camera placed on the screen (see Figure 1). Gaze data were synchronized to the preceding data (by manually starting gaze analysis when the subject started pedaling). The intuitive assumption was that, when the face of the participant was visible, he or she was looking at the screen, the alternative being that the participant would look mainly at the ground during intense effort. A percent ratio was defined between the amount of time spent looking at the screen and the total exercise time. There is of course a clear limitation in

Table 1. *Characteristics of the Two Experimental Groups*

Variables	Video *M*	Video *SD*	Video + music *M*	Video + music *SD*
Age (years)	23.00	0.62	22.83	0.62
BMI (kg/m^2)	23.11	1.74	21.98	1.51
Waist-to-hip ratio	0.82	0.05	0.80	0.05
Physical activity level (METs-min/week)	5171.25	2592.342	4955.68	5468.68
$V_{O_{2peak}}$ (mL/min/kg)	48.81	9.71	47.26	9.97

NOTE. BMI: Body mass index; METs: Metabolic equivalents; $V_{O_{2peak}}$: Predicted peak oxygen consumption.

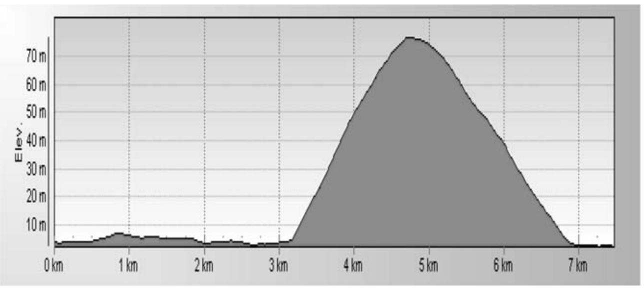

Figure 3. *Course profile composed of the succession of a flat, uphill, and downhill phase.*

using head orientation as a gaze behavior indicator. In this exploratory study, we only could use a video camera, which is a first (relatively easy) step in the direction of using gaze as an indicator of attention allocation during exercise. To our knowledge, this has not been done in previous studies on the role of virtual reality in exercise. Our reasoning was the following: if the participant's head was away from the screen (which was easily detected using a simple webcam), we were positive about the fact that he or she was not looking at the screen. If the participant's face was completely visible via the webcam (placed on top the display screen, facing the participant), we were sure he or she was looking at the screen. The limitation of this technique was obviously that we could not access which visual cue the participant was looking at, which would have required an eye tracker and synchronization of eye data with the screen content. However, we decided that our approach was sufficient for a first step. Moreover, the question of whether gaze location is a direct indicator of attention allocation is still a matter of debate. In other words, is it certain that I pay attention to the exact cue I am looking at? (See, for example, Henderson, 2003.)

2.3.3.3 Attentional Focus. Following recommendations from Baden et al. (2005) and from Tenenbaum and Connolly (2008), a 10 cm visual analog scale ranging from 0 (external thoughts, daydreaming, environment) to 10 (internal thoughts, how body feels, breathing, technique) was used to measure the participant's attention focus during exercise. This scale is designed to represent the continuum of attention strategies from pure dissociation (0) to pure association (10) (Tenenbaum & Connolly, 2008, p. 707). At the end of each session, participants were asked to report what percentage of their thoughts was either dissociative or associative (Baden et al., 2005).

2.3.3.4 Commitment Check. A French back-translated version of the commitment check questionnaire validated by Tenenbaum et al. (1999) was used to measure a "participant's commitment to, and effort investment in, the task" (Tenenbaum & Connolly, 2008, pp. 707–708). Given that no French version is available, these items were translated into French following the standardized back-translation techniques. Thus, following completion of the exercise, participants were asked to report their commitment by means of the following three questions: "(i) How committed to the task were you while performing? (ii) How well do you think you tolerated the effort associated with this task? and (iii) How much effort did you invest in the task?"

(Hutchinson & Tenenbaum, 2006, p. 468). In this study, the original answer scale (Likert-type scale ranging from 0 to 5) was replaced by a 10 cm visual analog scale in order to capture fluctuations more precisely.

2.3.3.5 Physical Activity Enjoyment. A French back-translated version of the physical activity enjoyment scale (PACES) validated by Kendzierski and DeCarlo (1991) was used to measure the quantity of perceived enjoyment during an exercise. This scale is composed of 18 seven-point bipolar items (e.g., I feel bored…I feel interested). In this study, the original answer scale was also replaced by a 10 cm visual analog scale and all items were summed to obtain a global scale score ranging from zero to 180. This questionnaire was completed by all participants at the end of each exercise session. The internal consistency of this questionnaire is ideal ($\alpha_{t0} = 0.93$; $\alpha_{t1} = 0.96$; $\alpha_{t2} = 0.97$; $\alpha_{t3} = 0.96$) regarding recommendations ($\alpha > .70$, modest; $\alpha > .80$, acceptable) from the literature (for more detailed information see Cortina, 1993; Helms, Henze, Sass, & Mifsud, 2006; Nunnally & Bernstein, 1994; Streiner, 2003).

2.3.4 Statistical Analysis. Three-way ANOVAs were applied to the behavioral data, with time (four sessions: T0 to T3) and phase (three course phases: flat, uphill, downhill) as intragroup factors and modality (two modalities: video and video + music) as a between-group factor. However, the attentional, commitment, and physical activity enjoyment data were examined with a two-way ANOVA, with time (four sessions: T0 to T3) as an intragroup factor and modality (two modalities: music-VR and VR) as a between-group factor. Finally, gaze data were submitted to a three-way ANOVA, with time (three sessions: T1 to T3) and phase (three course phases: flat, uphill, downhill) as intragroup factors and modality (two modalities: video and video + music) as a between-group factor.

3 Results

3.1 Phase Duration

A significant difference was observed between course phases, $F(2,20) = 54.52$, $p < .001$. In particular, downhill phase duration was reduced, as compared to flat and uphill durations, $F(1,10) = 67.15$, $p < .001$. However, this simple main effect was mainly due to the topology of the course (relative phase lengths and slopes). More importantly, a significant interaction effect was observed between time (task repetition) and modality, $F(3,30) = 3.6$, $p < .025$, revealing a differential effect of task repetition depending on modality (see Figure 4). For all phases, a significant decrease in duration was observed between T0 and T3 for the video + music condition $F(3,15) = 8.62$, $p < .005$, whereas no significant effect of task repetition was observed within the video condition $F(3,15) = 1.02$, $p > .05$. In other words, phase duration was reduced with task repetition, for all phases, in the video + music condition, which was not the case in the video condition.

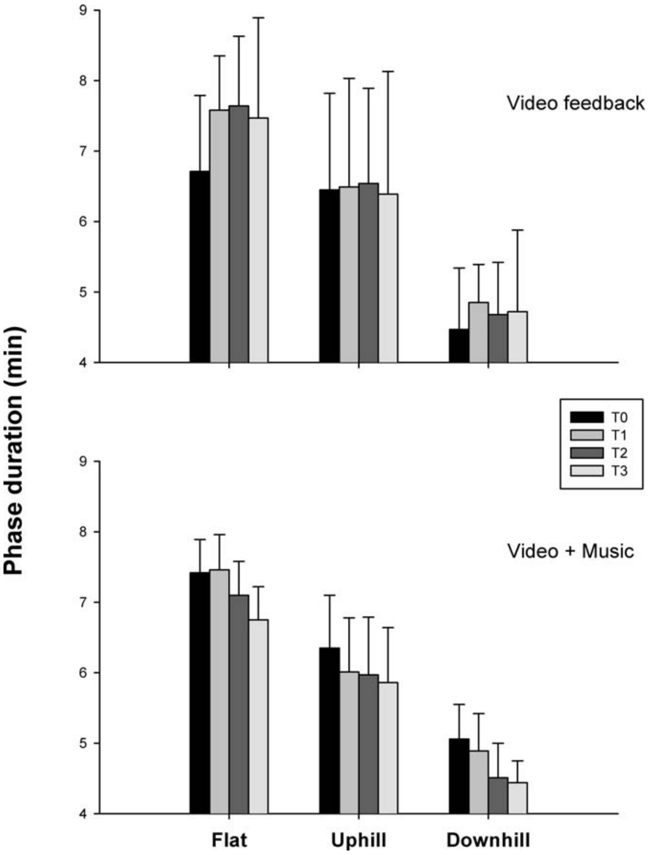

Figure 4. *Average phase duration (and SD), in minutes, as a function of task repetition (T0 to T3) and modality (video feedback only or video + music).*

3.2 Heart Rate

To further analyze how duration effects were related to exertion, we focused next on heart rate analysis. We specifically analyzed, for each participant and each repetition of the task, mean heart rate across course phases. In accordance with the course topology, we observed a significant phase effect, $F(2,20) = 93.03$, $p < 0.0001$, showing that average heart rate was dependent on course topology (and exercise intensity, with average heart rate being higher in the uphill phase, as compared to flat and downhill phases). The average values of heart rate were 126, 163, and 147 bpm, for flat, uphill, and downhill phases, respectively. Finally, a significant interaction effect was observed between time (task repetition) and modality (video + music vs. video). Figure 5 shows, in accordance with duration effects reported previously (overall phase duration diminishing with task repetition in the video + music condition) that, for all phases, the average heart rate tended to increase with task repetition in the case of video feedback associated with music listening and not in the case of video feedback alone. The pattern of results was similar for power analysis.

3.3 Gaze Analysis (Time Spent Looking at the Screen)

Gaze time analysis was only performed during sessions with music and/or visual stimulation (i.e., T1-T2-T3). The three-way analysis of variance indicated a significant effect of task repetition, $F(2,20) = 4.31$, $p < .05$. In the first session, participants spent, on average, more than 73% of the course duration gazing at the screen. However, this ratio dropped down to about 60% during the second session and to 50% during the third session. One can easily guess that participants learned the course profile over sessions, so that they needed to gaze at the screen less. We also observed a phase effect $F(2,20) = 6.25$, $p < .01$. On average, participants spent about 55% of the time looking at the screen in the uphill phase, as compared to about 66% in the flat and downhill phases. Finally, we observed an interaction effect between phase and modality, $F(2,20) = 4.47$, $p < .025$. Post hoc analysis revealed that in the video + music condition, the percentage (%) of time looking at the screen was significantly reduced in the uphill phase (45%), as compared to flat and downhill phases (about 65%), $F(2,10) = 10.701$, $p < .001$, which was not the case in the video condition. Last, task repetition significantly reduced the percent of time looking at the screen only in the video + music condition, $F(2,10) = 4.2886$, $p < .05$. Figure 6 represents gaze data.

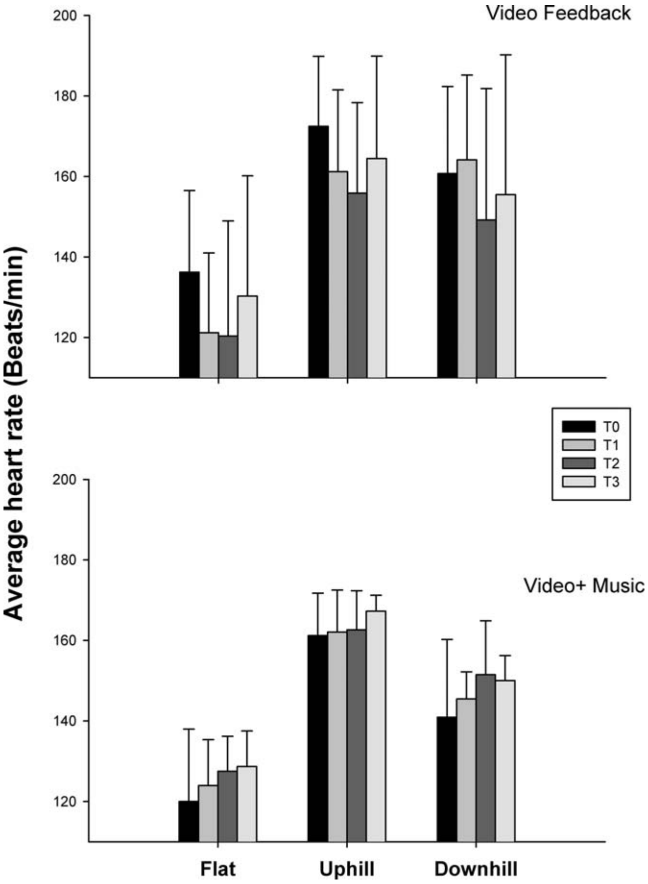

Figure 5. *Average heart rate (in beats per minute), as a function of task repetition (T0 to T3) and modality.*

3.4 Attentional Focus

Results from the two-way ANOVA exhibited a significant effect of time (task repetition), $F(3,30) = 3.69$, $p = .02$. The Student Newman-Keuls post hoc test revealed a significant reduction in association between T0 and T1 ($p < .05$), and no significant differences among T1, T2, and T3. The average values of reported association were around 6 for T0 and around 4 for T1 to

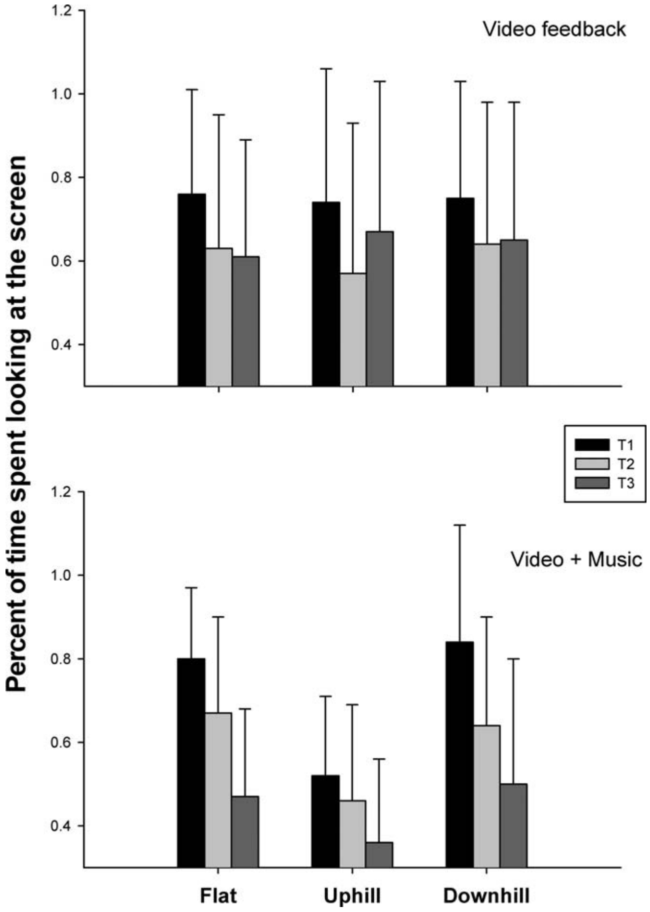

Figure 6. *Gaze behavior, expressed in percent of time spent looking at the screen, as a function of task repetition (T1 to T3) and modality.*

T3, with 10 representing maximal association and 0 maximal dissociation. No significant effects were found for modality, $F(1,10) = 0.02$, $p = .89$. The average values of reported association are illustrated in Figure 7.

3.5 Commitment Check

Concerning the task commitment question, a significant time effect was found, $F(3,30) = 3.50$, $p = .03$. With a value of 10 representing maximal commitment (on a 0–10 scale), post hoc analysis revealed that participants were less engaged in the task across sessions (from T0, with an average value of 7.9, to T3, with an average value of 6). Additional analysis revealed a significant interaction effect between modality and time (task repetition), $F(3,30) = 3.21$, $p < .05$. Figure 8 shows that in the video modality, task commitment was reduced across sessions, $F(3,15) = 4.27$, $p < .05$, going down from about 8 to less than 5, which was not the case in the video + music modality (with an average value around 7 across sessions). Finally, no significant effects were observed for perceived task tolerance and effort investment items.

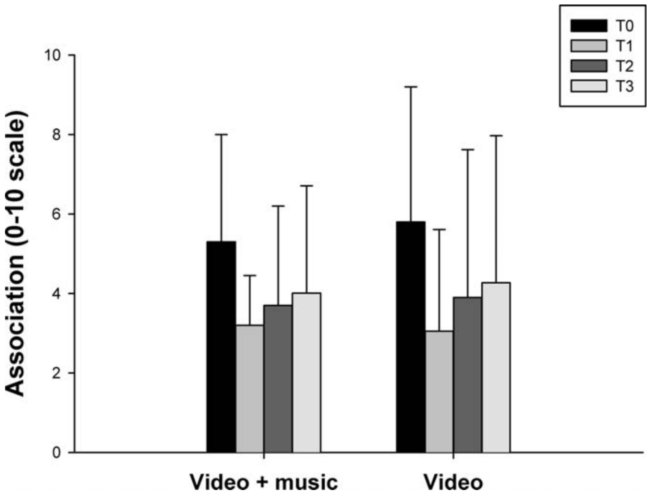

Figure 7. *Average reported association (and* SD*), as a function of modality and task repetition.*

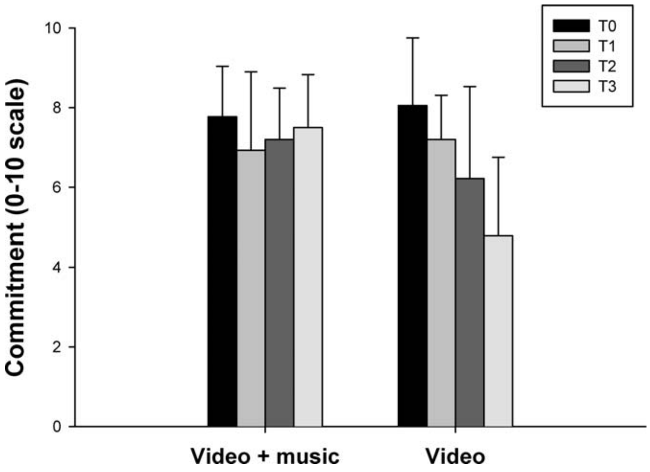

Figure 8. *Average reported commitment (and* SD*), as a function of modality and task repetition.*

3.6 Physical Activity Enjoyment

The two-way ANOVA revealed a significant effect of time, $F(3,30) = 3.20$, $p < .05$. The Student Newman-

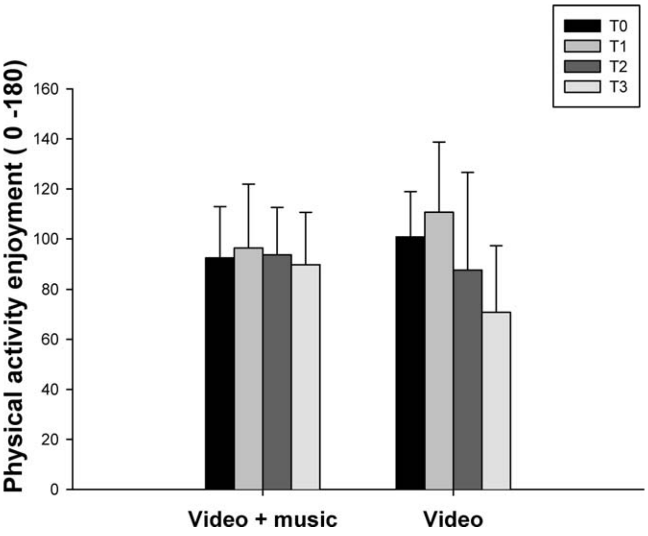

Figure 9. *Average reported physical exercise enjoyment (and SD), as a function of modality and task repetition.*

Keuls post hoc test indicated a significant decrease of physical activity enjoyment between T1 and T3 ($p < .05$), with average values of 100, 90, and 80 for T1, T2, and T3, respectively, on a 0–180 scale. No significant effects were found for modality, or the interaction between time and modality, $F(3,30) = 1.82$, $p > .05$. Nonetheless, we observed, as illustrated in Figure 9, a tendency to a reduction in enjoyment for the video modality between T1 and T3, with average values going from 110 down to 70.

4 Discussion

The purpose of this study was to experimentally manipulate sensory input to a participant exercising on an ergometer, to evaluate the effect of this input on performance, enjoyment, and attentional focus during a cycling task performed on a computer-controlled ergometer, with force feedback proportional to the virtual slope of a cycling course. Moreover, the experiment was specifically designed to study task repetition and task intensity effects. Two sensory modalities were tested in two separate groups of participants. In the first condition (video), participants watched a prerecorded video of a real course, whose display speed was controlled by VR software and was proportional to the participant's pedaling speed. In the second condition (video + music), participants listened to their favorite music while exercising.

4.1 Performance

First, as could be intuitively expected, the results showed a global exercise intensity effect on performance (duration, heart rate, and power). These measures are indeed sensitive to the slope profile of the course. This effect can be explained, mainly, by a mechanical effect (simulation of the slope of the road with a variable resistance force applied to the rear bicycle wheel). Overall, the present results do not indicate any simple effect of the modality factor (i.e., video + music vs. video). However, an interaction effect was obtained between modality and time (task repetition). Indeed, a significant decrease in exercise duration with exercise repetition was found in the video + music condition. Conversely, no significant variation was found for the video condition. This pattern of results suggests that music diverted participants' attention from the exercise, and might favor performance, whereas video feedback alone does not have any significant effect. This result is consistent with the pattern of results reported by Mac Rae et al. (2003), suggesting that music favors exertion.

4.2 Gaze Behavior

Across all experimental conditions, participants spent more than half of the exercise time (66%) looking at the visual feedback. However, gaze analysis revealed a decrease in the percent of time gazing at the screen over sessions for both groups. This might be explained by the fact that the video film course was identical across sessions. As a consequence, when a novelty effect had passed and/or learning of the course occurred, gaze attraction to the video feedback decreased accordingly. We also suggest a differentiated use of the video feedback over sessions. Indeed, participants seem to use visual feedback to estimate their position and thus their progress in the course. Another assumption, which has yet to be tested by a more detailed analysis of gaze, is that visual feedback (over sessions) allows participants to anticipate, for example, the end of the uphill phase. In order to do so, we obviously need a more sophisticated gaze analyzing system, coupled to the VR software.

Finally, the results showed a phase (i.e., flat, uphill, and downhill) effect on the time spent gazing at video feedback, but exclusively for the video + music modality. Indeed, participants listening to music during exercise appeared to be less attentive to video feedback when exercise intensity was higher (i.e., in the uphill phase). Inversely, participants involved in the video feedback condition continued to look at video feedback when exercise intensity increased. Therefore, these results suggest, for the video + music group, a different use of video feedback in comparison to the video group. These results clearly address the problem of the functional status of sensory feedback during exercise. Indeed, it is probable that this decrease of the time spent gazing at video feedback may have been influenced not only by the fact that participants have learned the video film, but also by exercise intensity and by the nature of sensory stimulation. In particular, it seems that the addition of music to the video feedback during exercise results in a more sophisticated use of the video feedback, this latter becoming more attuned to the course profile.

However, gaze analysis used in this study did not allow us to distinguish gazing strategies of participants (i.e., participants looking at the video feedback for brief durations, as compared to participants looking continually at the video scene), and did not allow us to distinguish between gazing zones in the visual scene. Regarding this, a more precise gaze analysis (in both temporal and spatial terms, using an eye tracker) should be conducted in future research studies.

4.3 Attentional Focus

As hypothesized, participants report less association (more dissociation) in the presence of video feedback (as compared to the first exercise session). However, no difference was observed between the conditions video and video + music. These results confirm, as suggested by Annesi and Mazas (1997), that VR exercise equipment may favor a dissociation of attentional focus.

4.4 Commitment to the Task

In contrast to Annesi and Mazas (1997), our results show that VR did not induce long-term commitment to the task. More specifically, commitment was reduced with task repetition for the video-feedback-only group. However, adding music listening resulted in a stable reported commitment across sessions.

4.5 Physical Activity Enjoyment

The results from this study demonstrate that neither the video nor the video + music condition represents a significant means to improve enjoyment during exercise performed with VR equipment. This is in contrast with Plante et al. (2003), who reported a significant increase of enjoyment during a single VR exercise session. This discrepancy might be explained by methodological differences (exercise type, single vs. repeated exercise sessions) between the studies.

5 Conclusions

At a first level of analysis, we observed that sensory stimulation while exercising resulted in participants being distracted from the exercise intensity, as indicated by self-report. It is thus possible to hypothesize that VR exerts a dissociative role during exercise (as reported in previous studies), but also that music associated with video feedback has no decisive effect. However, we also observed that commitment to the task significantly decreased over the sessions among participants involved in the video condition. This latter pattern of results is in concert with performance analysis. Indeed, in the video + music condition, physical exertion (as evaluated by average heart rate and exercise duration) increased over sessions; this was not the case in the video condition. Based on these results, it is probable that video feedback alone, even coupled to the participant's behavior, does not represent a panacea to induce long-term commitment and improve performance (see Mac Rae et al., 2003), and that adding music to video feedback has a beneficial influence at both the psychological and behavioral levels. Caution is warranted before concluding that music has a key role here, as compared to visual feedback. In our experimental conditions, participants could listen to different tracks during the consecutive training sessions. We cannot exclude the possibility, thus, that music triggered a novelty effect, while participants were training on the same track across sessions. Even if it is experimentally difficult, future work should deal with the effect of controlled and combined manipulations of sound and vision stimulation on long-term performance and enjoyment during a virtual cycling task.

Moreover, gaze analysis clearly demonstrates that video feedback is used in the presence of music. More precisely, the time spent looking at the display screen was modulated not only by the repetition of an exercise on a given track but also by exercise intensity. This time was significantly reduced during the uphill phase, as compared to flat and downhill phases. This result suggests that, in the video + music condition, participants make a differential use of visual information as a function of exercise intensity, and thus that the association-dissociation attentional focus balance varies as a function of exercise intensity, as long as gaze behavior is accepted as an objective indicator of attentional focus. In addition, adding music listening to VR training seems to contribute to long-term exercise commitment and enhanced performance. We thus suggest that, when participants are allowed to listen to music during exercise, they make strategic use of visual information, gazing at the screen at key moments during the course. Future studies using more sophisticated gaze analyzing systems will investigate this hypothesis that music contributes to a more efficient regulation of behavior.

In relation to the aforementioned studies on VR exercise, which suggest a positive role of interactive virtual environments on physical activity, these results demonstrate that the enhancement of performance and dissociation is dependent on complex interactions between exercise intensity and sensory information. Sensory information can be distinguished between external information (i.e., not linked to exercise, e.g., music but also landscape in the video scene) and internal information, linked to exercise. In order to achieve a better understanding of these interactions, future experimental studies should systematically manipulate the status of visual information in a VR setting. It appears relevant to study a continuum starting from a stimulation disconnected from the participant's activity (i.e., film or television) to an interactive visual stimulation in which the participant can control not only his or her displacement speed (as in our work), but also his or her trajectory.

This study also suggests the interest of gaze direction analysis as an instrument to examine attentional processes related to a VR exercise. This method needs to be further developed, in particular with more precise VR equipment in order to facilitate the estimation of gaze strategies (i.e., fixation locations, fixation times). Additionally, we attempted to influence attentional focus by a manipulation of experimental conditions with minimal instructions given to the participants (i.e., to complete the track). Since attentional focus inevitably has a subjective aspect, a controlled manipulation of instructions might be tested. In particular, it is possible to test, in conjunction with the manipulation of sensory information, the effects of instructions aimed at favoring a focus of participants' attention on their movements (e.g., to keep a regular cadence) or on the movement effect (e.g., to maintain a constant distance with a virtual opponent).

Finally, in the general context of virtual reality and human behavior analysis, one might argue that the video feedback we used was light, since the participants could only control the speed of a prerecorded film of a real course (by pedaling faster or slower). This was in fact quite different from a situation in which participants could control their trajectory in a virtual environment. Obviously, as mentioned earlier, future work will involve direct comparisons between a video context and a virtual environment context, in terms of adherence and motivation to perform physical exercise. However, we still want to characterize our experimental situation as virtual reality, since one fundamental aspect of virtual reality is interactivity. In our case, video and force feedback involved interactivity between the participant and the virtual course. Secondly, we used a commercially available system that was primarily designed for athletes preparing a future race on a real competition track. We think it is interesting to study how such a device could be adapted to the general population, in a fitness objective, in the general context of the development of exergames and serious games. In other words, is exercising within a virtual environment susceptible to favoring performance, adherence, and enjoyment? In relation to previous studies, we suggest that our study makes a modest contribution to this ongoing question. We also note that in the field of virtual cycling, some systems (such as Tacx® or Computrainer®) offer both real videos (as in our case study) and virtual environments for training. Clearly, the trade-off between the realism of a real course video and the interactivity of a virtual environment is a matter for the development of studies and the evolution of virtual cycling.

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