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Immersive virtual reality and its influence on physiological parameters in healthy people
Realidad virtual inmersiva y su influencia en parámetros fisiológicos de personas sanas

Gustavo Rodríguez-Fuentes, Pablo Campo-Prieto, Xosé Carlos Souto, José María Cancela Carral
Instituto de Investigación Sanitaria Galicia Sur (España), Universidad de Vigo (España)

Abstract. Exergames is booming recent times, as they are motivating and promote physical exercise and healthy lifestyle habits. Immersive virtual reality (IVR) exercise programs could be compared to traditional training programs. A starting point for this would be to explore the physiological responses that can be generated by its use. Therefore, the main objective was to evaluate the response across certain physiological indicators (heart rate, blood pressure and stress) after an IVR exergame exposure in a sample of healthy adults, and secondarily to explore its feasibility, safety and usability as a tool to facilitate physical exercise. 37 healthy adults (22-54 years, 54.1% women) participated in the study. They carried out one exergaming session with the HTC Vive Pro™ hardware. All participants completed the IVR session without significant adverse effects. All physiological parameters evaluated increased significantly in relation to pre-intervention levels. Regarding to secondary outcomes, rating of perceived exertion (RPE) corresponded to a moderate to intense exercise (6.3±0.5/10 on the CR10 Borg Scale), the intervention was considered safe (1/37 reported a moderate stomach awareness in Simulator Sickness Questionnaire), with good usability (>76% in System Usability Scale), positively valued by the sample (0.05/4 negative experience scores in Game Experience Questionnaire-post game), and 100% of the sample reported a good or very good experience and would recommend it. These findings support that our IVR exergame session was feasible and can be compared to a moderate to intense physical activity, as it involved similar RPE with significant increases in heart rate, blood pressure and salivary cortisol levels.
Keywords: virtual reality exposure therapy; exergaming; cortisol; heart rate; blood pressure; health promotion; physical therapy modalities.

Resumen. Los videojuegos activos o exergames están en auge últimamente, ya que motivan y promueven el ejercicio físico y los hábitos de vida saludables. Los programas de ejercicio con realidad virtual inmersiva (RVI) podrían compararse con programas de entrenamiento tradicionales. Un punto de partida para ello sería explorar las respuestas fisiológicas que puede generar su uso. Por tanto, el objetivo principal fue evaluar la respuesta a través de ciertos indicadores fisiológicos (frecuencia cardiaca, presión arterial y estrés) después de una exposición a un exergame RVI en una muestra de adultos sanos, y, en segundo lugar, explorar su viabilidad, seguridad y usabilidad como herramienta para facilitar el ejercicio físico. Participaron en el estudio 37 adultos sanos (22-54 años, 54,1% mujeres). Realizaron una sesión de exergaming con el hardware HTC Vive ProTM. Todos completaron la sesión de RVI sin efectos adversos significativos. Todos los parámetros fisiológicos evaluados aumentaron significativamente en relación con los niveles preintervención. En cuanto a los resultados secundarios, el esfuerzo percibido correspondió a un ejercicio de moderado a intenso (6,3±0,5/10 en la escala CR10 de Borg), la intervención se consideró segura (1/37 informaron de una conciencia estomacal moderada en el Simulator Sickness Questionnaire), con buena usabilidad (>76% en la System Usability Scale), valorada positivamente por la muestra (0,05/4 puntuaciones de experiencia negativa en el Game Experience Questionnaire-postjuego), y el 100% de la muestra informó de una experiencia buena o muy buena y la recomendaría. Estos resultados respaldan que nuestra sesión de exergame RVI fue factible y puede compararse con una actividad física de moderada a intensa, ya que supuso un esfuerzo percibido similar con aumentos significativos de la frecuencia cardiaca, la presión arterial y los niveles de cortisol salival.
Palabras clave: terapia por exposición a realidad virtual; exergaming; cortisol; frecuencia cardiaca; presión arterial; promoción de la salud; modalidades de fisioterapia.

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Pablo Campo-Prieto
pcampo@uvigo.es

Introduction

Taking part in physical activity and/or exercise generates a varied response across different physiological parameters. Among them, there are positive effects on Heart Rate (HR) - the resting heart rate, the maximal heart rate, and the submaximal heart rate in patients with cardiac issues (Lloyd-Williams et al., 2002). Blood Pressure (BP) is also positively impacted (Pescatello et al., 2004), with studies showing that physical activity causes it to fall both at rest and during daily activities (Cornelissen & Fagard, 2005; Cornelissen & Smart, 2013; Dickinson et al., 2006; Kelley et al., 2001; Kelley & Kelley, 2000; Whelton et al., 2002). At the same time, physical exercise, as a physiological and psychological stressor, activates the hypothalamic-pituitary-adrenal (HPA) axis, and the secretion of cortisol increases in response to this situation of physical stress (Hackney, 2006).

Cortisol is a hormone generated by the adrenal glands. Under normal conditions, cortisol secretion varies according to the time of day, as it is linked to circadian rhythms. Its highest levels occur 30 minutes after waking and progressively decrease during the day until sleep, at which time they begin to climb again (Inder et al., 2012; Kaushik et al., 2014; Laudat et al., 1988; Pruessner et al., 1997). However, when a physical or mental challenge presents itself, or a threat is perceived, the HPA axis is activated and an increase in cortisol occurs. Once the challenge has been resolved, cortisol levels return to their basal state (Smith, 2003). These states and fluctuations are important, as abnormal cortisol levels provoke changes in the immune system and an inflammatory response (Kaushik et al., 2014).

Cortisol levels, as detected both in serum and saliva, also increase according to the type and intensity of exercise performed (Anderson et al., 2016; Chtourou et al., 2014; Davies & Few, 1973; Gatti & De Palo, 2011; Jacks et al., 2002; McGuigan et al., 2004), and the study of these levels is therefore used to assess the acute and chronic effects of training (Wunsch et al., 2019). Therefore, cortisol levels are used as a biomarker of psychological and physical stress (Hellhammer et al., 2009; Jacks et al., 2002; Roberts, 2019). To analyze the concentration of cortisol, both blood and saliva tests are commonly used (Pearlmutter et al., 2020). As a non-invasive method which has a high correlation with serum levels, salivary cortisol analysis is widely used (Hellhammer et al., 2009; Kirschbaum & Hellhammer, 1989, 1994; Vining et al., 1983), although it can be affected by the consumption of food or coffee, or by smoking or chewing gum (Roberts, 2019).

Exergames, or active video games, are increasingly used by society, as they are highly motivating and encourage physical exercise and healthy lifestyle habits (Gao & Lee, 2019). This represents a paradigm shift in the use of traditional video games related to more sedentary behaviours (Castro Sánchez et al., 2015). Some studies have recently explored whether immersive virtual reality (IVR) exercise programs could be compared to traditional physical exercise programs (Lange et al., 2012; Liao et al., 2020; McDonough et al., 2020; Ozkul et al., 2020; Silva et al., 2021).

It is noteworthy that there are other previous studies where the influence of immersive and non-immersive virtual reality on heart rate (Y. S. Kim et al., 2022; Silva et al., 2021) and blood pressure (McDonough et al., 2020; Saiz-González et al., 2023; Silva et al., 2021) compared to other more traditional exercise programs (conventional training (Silva et al., 2021), treadmill walking and cycling (McDonough et al., 2020; Saiz-González et al., 2023).

So far these studies have focused on whether these programs are feasible for different populations and whether the improvements in physical, cognitive and functional abilities generally attributed to traditional exercise, can be replicated or even improved by the use of fully (Bank et al., 2018; Barsasella et al., 2021; Benham et al., 2019; Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a; Jones et al., 2018; A. Kim et al., 2017; Murray et al., 2007; Phu et al., 2019) or non-immersive (Maranesi et al., 2022; Wu et al., 2023) virtual environments. Kim et al., 2022 addressed their study to detect the presence of cybersickness by analyzing the impact of a 2-minute IVR exposure on physiological parameters, including blood tests. Other studies investigate the VR aftereffects in commercial exergames (Szpak et al., 2020). However, to the best of our knowledge, physiological responses, such as raised levels of cortisol in the saliva after exposure to IVR exergames have not yet been studied.

The main objective of this research was to assess the response through certain physiological indicators (heart rate, blood pressure and stress) after exposure to an IVR exergame in a sample of healthy adults, and to explore its usefulness as a tool to facilitate physical exercise. A secondary objective was to report on the safety and usability of the IVR tool, as well as the participant satisfaction with the experience.

Materials and Methods

Participants

An information and dissemination campaign of the proposed study was carried out via e-mail to the university community of the Pontevedra Campus (Universidade de Vigo, Spain). Thirty-seven volunteers attended a scheduled informative talk about the study in our lab. The exclusion criteria applied to the sample were: failure to respond correctly to the clinical protocol; presence of cardiovascular, pulmonary or musculoskeletal pathologies that, according to the physiotherapist's criteria, could affect the individuals' ability to participate in the study; presence of severe visual impairment that could interfere with the ability to view the IVR simulation. Finally, all the volunteers were part of the study (n=37), healthy adults aged between 22 and 54 years (31.40±8.91), 54.1% of them being women. Once the aims and methods were explained, informed consent was obtained. The study was approved by the Ethics Committee of the Faculty of Physiotherapy of the University of Vigo (no. 205/2020-2). Table 1 shows the main demographic characteristics of the sample.

Table 1.
Characteristics of the sample and conditions the where the protocol was developed.

			Total (n=37)
Participants	Age (years)		31.40 (8.91)
	Gender (Female)		54.1%
	IVR Experience	1st Time	86.5%
		Occasional User	13.5%
	Pharmacotherapy (Yes)		5.4%
Room	Temperature (°C)		23.17 (0.80)
	Humidity (%)		40.25 (6.67)
	Activity time		10:00-12:00

IVR: Immersive Virtual Reality

Intervention

This study took place in the HealthyFit Physical Activity Lab (Faculty of Education and Sports Sciences, University of Vigo, Spain). The immersive virtual environment was developed using the HTC Vive Pro™ device. This system consists of: a head-mounted display, two wireless handheld controllers, two external sensors, a wireless adapter, the Viveport software support (https://viveport.com accessed on 15-10-2022), and a desktop computer (CPU: Intel Core I7 7700 3.6 GHz, 1 Tb HDD Sata 3.5 and NVIDIA GeForce RTX 2070 GPU). A LED screen was used to guide the activities and configure the technical aspects of the device. A gaming area of 5 m2 was defined following the manufacturer's recommendations. (Figure 1).

The exergame used for the study was *BOX VR* (available in the library of Steam.com), which simulates being in a gym doing boxing training. This game has been used in our previous studies (Campo-Prieto, Rodríguez-Fuentes, & Cancela-Carral, 2021b; Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a). The appearance of different stimuli requires not only coordinated movements of the upper limbs, trunk and head, but also of the lower limbs, thus changing the initial static standing position with squats and lateral displacements. The music helps to perform the exercises required by the exergame. The exergame was selected as a multi-component training, highly recommended for the general population and that provokes hard or very hard exertion (depending on the personal user perform). All the participants performed this boxing-based exercise at the same exergame level and for the same duration: 6 min approx. (Figure 2).

Figure 1. Participant during a guided and supervised exergame session in HealthyFit Physical Activity Lab.

Figure 2. Screenshot of the proposed exergame (*BOX VR*).

Procedure

On the day set for the IVR exergame, the participants were instructed to collect a fasting saliva samples, using a polyester swab sampling device (Salivettes@; Sarstedt, Nümbrecht, Germany), which was chosen because it was non-invasive, eliminated the influence of pre-injection stress, and was easy to use. Saliva was collected at two time points: before and after the test. The participants were asked to refrain from eating, chewing gum, smoking, brushing teeth, consuming caffeine (coffee, cola) and drinking for three hours before the first saliva collection. They were also informed about and taught how to use the device. In all cases, the interventions took place in the morning (between 10-12 am) in the HealthyFit Physical Activity Lab. Before and immediately after the exergame test, saliva samples, heart rate and blood pressure values were recorded (HR and BP initial measures were collected after sitting for 5 min). Immediately after the intervention, the participants were also asked about their rating of perceived exertion, whether they had experienced any discomfort linked to cybersickness, and their experiences in using the IVR hardware and software.

Assessment tools

All participants completed the following evaluations:

a) Main variables:

1. **Concentration of Cortisol** through the analysis of salivary cortisol values. Samples were collected pre- and post-intervention. At the time of sample collection, all the participants were asked to fast until the IVR procedure had been performed. Saliva samples were collected in a plastic tube (Salivettes@; Sarstedt, Nümbrecht, Germany), and the participants were asked to collect 1.5 to 2 mL of unstimulated saliva. Samples were collected from everyone at two times: before and after the IVR intervention, which was itself performed between 60 and 90 minutes after the subjects had woken up, so as to minimize circadian rhythm variations. They were also asked not to use steroid-containing creams or inhalers, not to engage in any activity that would cause the gums in their mouth to bleed, and not to consume salivary stimulants such as ascorbic acid prior to sample collection. The saliva samples collected were immediately stored at -20 °C and sent to a biochemical laboratory (Lab. Valenzuela, Pontevedra, Spain) for further analysis. The samples were thawed and centrifuged at 4°C at 3,000 rpm for 3 min to obtain clear saliva. Free cortisol concentrations (nmol/l) were determined using a luminescence immunoassay for in vitro diagnostic quantitative determination of cortisol in human saliva (IBL International) (Wunsch et al., 2019).
2. **Heart Rate** was measured by using a My Smart Band 4 wristband and the My Fit 4.0.14 app version (Xiaomi, Haidian, Beijing). The average heart rate was taken pre-intervention and post-intervention. This tool has been used in our previous studies (Campo-Prieto, Rodríguez-Fuentes, & Cancela-Carral, 2021b, 2021a).
3. **Blood Pressure**, was measured by using OMRON M3 tensiometer, based on IntelliSense technology. It is clinically validated according to the European Society of Hypertension International Protocol. The Systolic BP (mmHg) and Diastolic BP (mmHg) were taken pre-intervention and post-intervention.

b) Secondary variables.

4. **Safety** of the immersive experience was calculated by means of the Simulator Sickness Questionnaire (SSQ) (Campo-Prieto, Rodríguez-Fuentes, & Cancela Carral, 2021)), translated into and adapted for Spanish (Campo-Prieto, Rodríguez-Fuentes, & Cancela Carral, 2021). This tool has been widely used to measure the frequency of cybersickness in the general population (Kennedy et al., 1993). The questionnaire was completed immediately after the intervention.
5. **Rating of Perceived Exertion (RPE)** was

calculated using the CR10 Borg scale (Borg, 1982). The questionnaire was completed immediately after the intervention.

6. Usability of the proposed using the System Usability Scale (SUS) (Brooke, 1995). The SUS was developed as a survey that allows practitioners to assess the usability of a product/service quickly and easily. SUS is a Likert type scale that is made up of 10 questions which are rated on a scale of 1 to 5. The resulting algorithm creates a score out of a possible 100 points (Hedlefs Aguilar & Garza Villegas, 2016). The survey was completed immediately after the intervention and the Spanish version was used (Hedlefs Aguilar & Garza Villegas, 2016).

7. Post gaming experience was evaluated by using the Game Experience Questionnaire (post-game GEQ) module (IJsselsteijn & de Kort, 2013) and an *ad hoc* satisfaction questionnaire. The GEQ is a questionnaire that consists of three modules (main module, social module, and post-game module). Module 3 assesses how they felt after the match. This module consists of 17 questions where the answers are scored according to the intensity of the players' feelings (where 0 is not at all and 4 is extreme). These questions are placed in a 4-component framework: positive experiences, negative experiences, tiredness and return to reality (Denisova et al., 2016). The ad hoc satisfaction questionnaire, consisting of 5 questions, was developed to identify the strengths and weaknesses of the intervention. These questions were also asked immediately after the intervention. Both questionnaires were used in Spanish and have already been used in previous research (Campo-Prieto, Rodríguez-Fuentes, & Cancela-Carral, 2021b; Campo-Prieto, Cancela-Carral, Machado de Oliveira, et al., 2021c; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a).

Data analysis

Descriptive statistics (mean, standard deviation, percentage, minimum and maximum) were used to represent the demographic characteristics of the sample. The normality of the data was examined employing the Shapiro-Wilks test, with a $p > 0.05$ indicating a normal distribution. Paired samples t test (Student´s T test) was used to test the difference in variables between pre-intervention and post-intervention with IVR.

Data analysis was executed with IBM-SPSS, (version 25.0), with the level of significance set at $p<0.05$.

Results

All participants completed the IVR session successfully without significant adverse effects. This is reflected in the responses to the SSQ questionnaire, which showed no serious adverse symptoms linked to cybersickness in any of the participants. Only 1/37 reported feeling a moderate symptom (stomach awareness), 7/37 reported mild symptoms related (difficulty focusing) on the end of the session, but most participants reported a total absence of symptoms related to virtual exposure. Additionally, the level of perceived exertion corresponded to the values for moderate to intense exercise (6.30±0.50/10 on the modified Borg scale).

The main findings were that after the IVR intervention, the physiological parameters analyzed (heart rate, blood pressure and cortisol concentration in saliva) increased in relation to their pre-intervention level (Table 2). Furthermore, usability for the IVR device were good (SUS values 76.6/100; 60.0-87.5), and the post-game experience was considered good with low values in the items related to negative experiences, measured with the GEQ post-game module (0.05±0.12/4) (Table 3). This perception is supported by the fact that 100% of the participants considered the experience as good or very good and would recommend it in their satisfaction questionnaire responses (Table 4).

Table 2.
Physiological parameters before and after immersive virtual reality test.

	Moment		Paired t-test			
	Pre- intervention Mean (SD)	Post- intervention Mean (SD)	95% CI		t	p
Heart Rate (bpm)	76.24 (10.65)	109.35 (15.62)	-40.20	-26.01	-9.466	0.001
Systolic BP (mmHg)	125.62 (15.78)	133.41 (20.84)	-11.92	-3.64	-3.812	0.001
Diastolic BP (mmHg)	77.92 (11.69)	82.54 (12.99)	-7.04	-2.19	-3.862	0.001
Cortisol Level (nmol/L)	2.95 (2.21)	3.61 (3.21)	-2.42	-1.11	-5.489	0.001

BP: Blood pressure; bpm: beats per minute; CI: confidence interval; SD: standard deviation.

Table 3.
Personal post game experiences after immersive virtual reality test.

		Mean (SD)	Min	Max
GEQ (Post-Game module)	Positive Experience	2.51/4 (0.93)	0.33	4.00
	Negative Experience	0.05/4 (0.12)	0.00	0.50
	Tiredness	0.82/4 (0.61)	0.00	2.50
	Return to Reality	0.46/4 (0.49)	0.00	1.67

GEQ: Game Experience Questionnaire; SD: standard deviation.

Table 4.
Ad hoc satisfaction questionnaire and main responses after immersive virtual reality test.

		Participants (n = 37)	
		n	%
How did you find the experience?	Good or very good	37	100%
What did you like the most?	It is a very entertaining activity	7	18.92%
	The environment in which it takes place and the guidance you receive (the immersive experience itself)	19	51.35%
	The exercise itself	11	29.73%
Was there anything you did not like?	No	30	81.08%
	The music was a bit too loud	1	2.7%
	Too short	1	2.7%
	Sore quads	1	2.7%
	Using a mask	1	2.7%
	Needed more work on the lower limbs	2	5.41%
	Headset was a bit heavy	1	2.7%
Would you recommend the IVR experience?	Yes	37	100%
	No	0	0%
Do you think this could be useful for people of your age? Why?	*Yes* Fun and Dynamic activity A good way to do exercise Good for improving co-ordination Improves concentration and self-confidence Entertaining Motivating Good for diverse groups of people to get started in doing exercise Good for when it´s impossible to go outside Good for people with complex health issues Good for all age groups and with a wide range of possible objectives	37	100%
	No	0	0%

IVR: Immersive Virtual Reality

Figure 3 shows the relationship between cortisol levels (pre- and post-intervention) in the subjects analyzed, there is an exponential growth of cortisol levels after completion of the IVR exercise. Additionally, Figure 4 shows the relationship between the post-intervention cortisol levels and exertion and indicates that low levels of RPE is related to low cortisol levels and high levels of RPE is related to high cortisol levels. It is important to note that in the RPE 5-8, the cortisol level is stable (4.6-5.0). Finally, Figure 5 shows the influence of cortisol level on blood pressure. The distribution shows very similar behaviour, with the exception of the 5 – 10 cortisol range, in which the systolic pressure rises much more than the diastolic pressure.

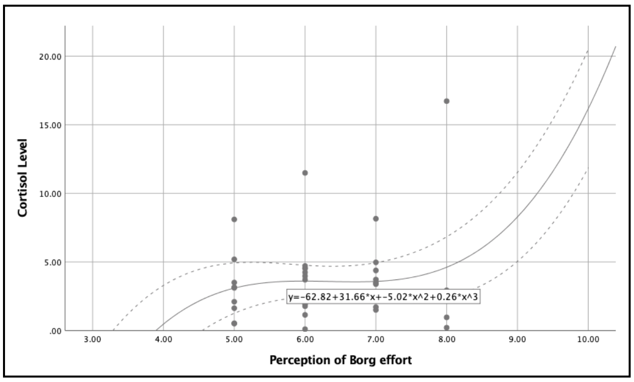

Figure 4. Distribution and relationship between post-intervention cortisol values and perceived exertion.

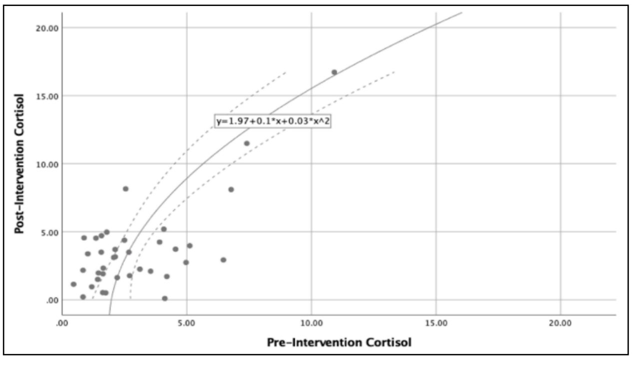

Figure 3. Distribution and relationship between the cortisol values before and after the intervention.

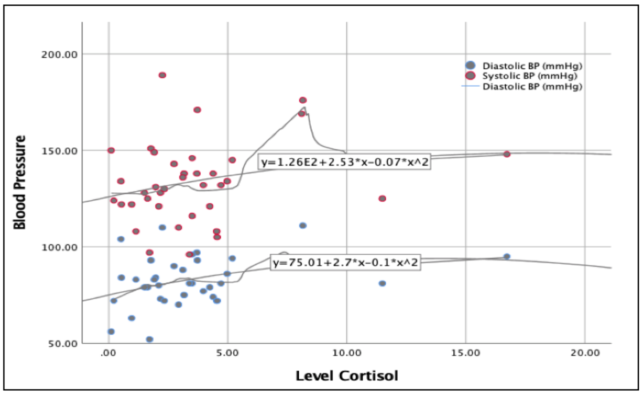

Figure 5. Distribution and relationship between blood pressure (systolic and diastolic) and post-intervention cortisol values cortisol.

Discussion

Our study evaluated the response of certain physiological parameters in a sample of healthy adults to participation in an immersive exergame. The findings indicate that participating in an IVR session involved a RPE similar to that of a moderate to intense activity, generating significant increases in heart rate, blood pressure and cortisol concentration in saliva.

The increase in heart rate and blood pressure following the performance of a one-off activity with these levels of RPE is in line with other studies (Feodoroff et al., 2019; González-Camarena et al., 2000; McDonough et al., 2020; Saiz-González et al., 2023; Silva et al., 2021). However, these studies differ from ours in several aspects. Thus, the intervention of González-Camarena et al. (2000), was not based on IVR but they investigated quadriceps work at 30% of the maximum voluntary contraction or cycling exertion at 30 or 60% of VO2max for 6 minutes or the study of Silva et al. (2021) which pointed out that systolic blood pressure decreased significantly immediately after the sessions (exergame and conventional exercise). The same outcome was founded by Kim et al. (2022), in the case of people who had suffered cybersickness after the exposure to IVR flight simulator. In our case, where we used a boxing-based exergame and probably the increase in post-intervention blood pressure may have been due to the overall movement demands (more exertion) and the absence of sickness symptoms could be related to virtual environments without accelerations or sudden changes of view as can however occur in a flight simulator. In addition, the fact that it was a single session - a one-off activity - may explain this increase in blood pressure, an aspect that leads us to suggest that longer interventions are needed clarify if certain types of IVR training (or programs) led to lower blood pressure.

McDonough et al. (2020) report that while systolic blood pressure was significantly higher in a 20 min session of IVR cycling than in a session of exergaming cycling (non-immersive), this was not the case when it was compared to a session of traditional exercise cycling. Similar results to McDonough et al. (2020) were published by Saiz-González et al. (2023), who found that IVR cycling and traditional cycling interventions significantly increased systolic blood pressure when compared to non-immersive VR cycling. They found no significant differences between IVR cycling and traditional cycling (both studies were also one-off sessions and not part of a long-term program). The results they found led Saiz-González et al. (2023) to claim that IVR may be as effective as traditional cycling in relation to cardiovascular health. In the light of this, our data could also be interpreted in this way, suggesting that IVR boxing may be a form of exercise with potential for certain clinical situations that, for whatever reason, do not favour traditional exercise - for example, in the case of patients suffering from functional impairment or having mobility issues.

The levels of cortisol in saliva also respond in a similar way to HR and blood pressure. Our data shows significant increase immediately after the IVR intervention. As reported in other studies (Anderson et al., 2016; Budde et al., 2010; Caplin et al., 2021; Hill et al., 2008; Jacks et al., 2002; Kudielka et al., 2009; McGuigan et al., 2004; Saiz-González et al., 2023), it appears that high-intensity exercise increases salivary cortisol values, while low to moderate intensity exercise either causes them to decrease, causes no change, or the variation recorded is not statistically significant. The IVR intervention detailed here was moderate to high intensity exercise, according to our sample's rating of perceived exertion (6.3 on a scale of 0-10). This data is similar to that recorded in a study carried out by Budde et al. (2010), with a sample of adolescents, or Hill et al. (2008), who analyzed what level of exercise intensity leads to an increase in circulating cortisol level. To do this, a 30-min intervention was designed, using a cycloergometer at 40, 60 and 80% of VO2max, and a sample of moderately trained active men with a mean age of 26 years. The results indicated that moderate to high intensity exercise causes an increase in cortisol levels, which is consistent with the data produced by our study, although the intervention carried out by Hill et al. (2008) is clearly different to this one.

Jacks et al. (2002) add some qualifiers to these results, as in their study it was only participants who exercised at a high intensity who significantly increased post-exercise salivary cortisol levels, and not those who exercised at a low or moderate intensity. Similar results were found by Begdache et al. (2022), who pointed out that cortisol level can be a gauge of workout intensity, since in their study, with a sample of 48 healthy college students made up of 23 athletes and 25 non-athletes who performed a cycling session at a minimum of 65% of age-adjusted maximal heart rate, the cortisol level increased only in the athletes. As the authors themselves suggest, this could be because the athletes performed the activity at a higher intensity than the non-athletes. All the above suggests that there are several factors at play, which means that further research is needed.

It can also be interpreted that the variation in cortisol levels depends on the training load in the case of athletes, or as pointed out by Kudielka et al. (2009), that it depends on the level of habituation to the stressor, since habituation to exertion or to a given stressor may lead to a decrease in cortisol levels as the sessions go on. This could explain our results, since for most of the sample (32/37), it was their first experience with IVR and there was, therefore, a lack of habituation to this type of stimuli and situation. The results are in line with the findings of Popovic et al. (2019), who indicate that untrained participants show a greater increase in cortisol levels than athletes after performing a progressive continuous cardiopulmonary exercise test on a treadmill, and also with Roberts (2019), who found that in a group of healthy college students, those who exercised regularly had a lower cortisol level post-exercise than those who did not. A similar situation can also be observed in the study by Parastesh et al. (2019), in which, after a session of exercise to exhaustion on an ergometer, fifteen female athletes found that there were no significant differences in cortisol levels pre- and post-intervention.

Regarding this habituation to the stressor, there is also the possible influence of a cognitive-emotional load (Kirschbaum & Hellhammer, 1994) on the cortisol level, which can occur when facing a new situation - as was the case in our research - and which could be similar to what athletes' experience when competing. Thus, despite habituation to high-intensity exercise, Viru et al. (2010) found that competition-like situations led to an increase in post-exercise cortisol level.

The physical exercise performed during this IVR intervention seems to be similar to and comparable with traditional physical exercise in terms of the variation shown in the physiological parameters analyzed (Lange et al., 2012; Liao et al., 2020; McDonough et al., 2020; Ozkul et al., 2020; Silva et al., 2021). However, the absence of study variables relating to physical condition and functionality only allows us to suggest this, and future studies are needed to analyze this aspect. There is also another parameter to consider, which may relativize the value of our findings and which also requires further research, and that is the duration of intervention. Our IVR intervention, which lasted approximately 6 min, resulted in an increase in heart rate, blood pressure and cortisol level in saliva. As noted previously, similar results in times like ours have also been seen in the work of González-Camarena et al. (2000), although with quadriceps or cycling work, not IVR. However, with their study using a cycloergometer intervention, Jacks et al. (2002) found that with a workout of less than 40 min there were no modifications in post-exercise cortisol levels. Other previously noted work carried out interventions that included VR+cycling of 12 (Saiz-González et al., 2023), 20 (Jacks et al., 2002), 50 (Borg, 1982) or 60 (Begdache et al., 2022) min. This disparity in intervention durations and outcomes calls for protocols to be put in place, and for further research, not only to see to what degree duration affects physiological parameters, but also to analyze what type of exergame could be more effective in inducing changes to physiological markers.

In addition, this intervention scarcely had any adverse effects, these being slight and residual, confirming good usability of the commercial HMD device and a very positive evaluation of the experience by the participants. This positive and motivating evaluation of IVR use is in line with previous studies (Barsasella et al., 2021; Benham et al., 2019; Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a; Duque et al., 2013; Liao et al., 2020; McDonough et al., 2020; Saiz-González et al., 2023), although there are also studies which state the opposite (Feodoroff et al., 2019). In any case, our results did not allow us to verify whether the presence of severe cybersickness symptoms would produce variations in the physiological parameters studied, nor whether a certain stability in these guarantees the absence of cybersickness, aspects to be evaluated in future studies. It is possible that the non-generation of cybersickness symptoms in our case is due to the fact that the exergame used does not lead to a conflict in the sample between its vestibular system and its visual perception of body movement (Y. S. Kim et al., 2022).

One benefit of this study – though it was not a study objective – was that it seems IVR training may encourage people to exercise, especially those with physical difficulties or a previous lack of interest, and that it may also promote adherence to such physical training programs (Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a; Rhodes & Kates, 2015), and also to programs promoting healthy living, and disease prevention and treatment – as other research has previously illustrated (Barsasella et al., 2021; Campo-Prieto, Cancela-Carral, Alsina-Rey, et al., 2022; Campo-Prieto, Cancela-Carral, & Rodríguez-Fuentes, 2022a, 2022b; Li et al., 2020; Liao et al., 2020; Park & Yim, 2016; Thapa et al., 2020; Winter et al., 2021). Initially, at least, this is suggested by what our sample reported when answering the SSQ, SUS, GEQ post-game module and ad hoc satisfaction questionnaire.

Limitations

Although our study suggests that the proposed IVR based on a boxing exergame can lead to moderate to high intensity exercise for the physiological parameters analyzed, as well as being motivating for the subjects, it is not without several limitations. Firstly, we only assessed the acute effects of the IVR on heart rate, blood pressure and cortisol in saliva immediately post-intervention but not at different times after the intervention (20, 30 or 60 minutes), so we do not know how long they remained increased, or how long it took them to return to their pre-intervention baseline values. Neither was it possible to determine whether this variation occurs at any time during a person's daily circadian rhythm. Secondly, the data obtained cannot be generalized to other ages (preadolescents, adolescents or older), or to populations with disease, or to other times of the day (afternoon or evening). Furthermore, the lack of a sample size calculation also precludes these generalizations. Regarding the measurement of the level of cortisol, the sensitivity of cortisol measurement is greater in blood than in saliva, which forces us to be cautious with the data obtained here, although it is a fact that saliva has the advantage of being easy to collect and of being a not-invasive method. The lack of control over the participants′ possible ingestion of coffee or food, of smoking or chewing gum, as well as the possible differences that may have occurred between the time of waking up and the taking of the initial sample of cortisol in saliva, or the time elapsed between waking up and taking part in the intervention – all of which may have altered the levels of cortisol in saliva or, at least, may not be the same as in a situation of total control over these variables - oblige us to be cautious.

Conclusions

The performance of the IVR session proposed by healthy young adults resulted in an increase in their heart rate, blood pressure and salivary cortisol level. This activity, when considering the subjects' RPE, was of a moderate to high intensity, similar to that of a traditional physical activity of similar intensity, with the added benefit of not generating any adverse effects and obtaining a very positive evaluation from the participants, which may favour their adherence to an exercise program. Future studies are needed to determine whether these changes occur at any time during the daily circadian rhythm, and to study their importance for cardiovascular health, and their possible relationship with the cybersickness symptoms.

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