Pooya Soltani

Virtual Swimming: A psycho-biophysical evaluation of an active video game.

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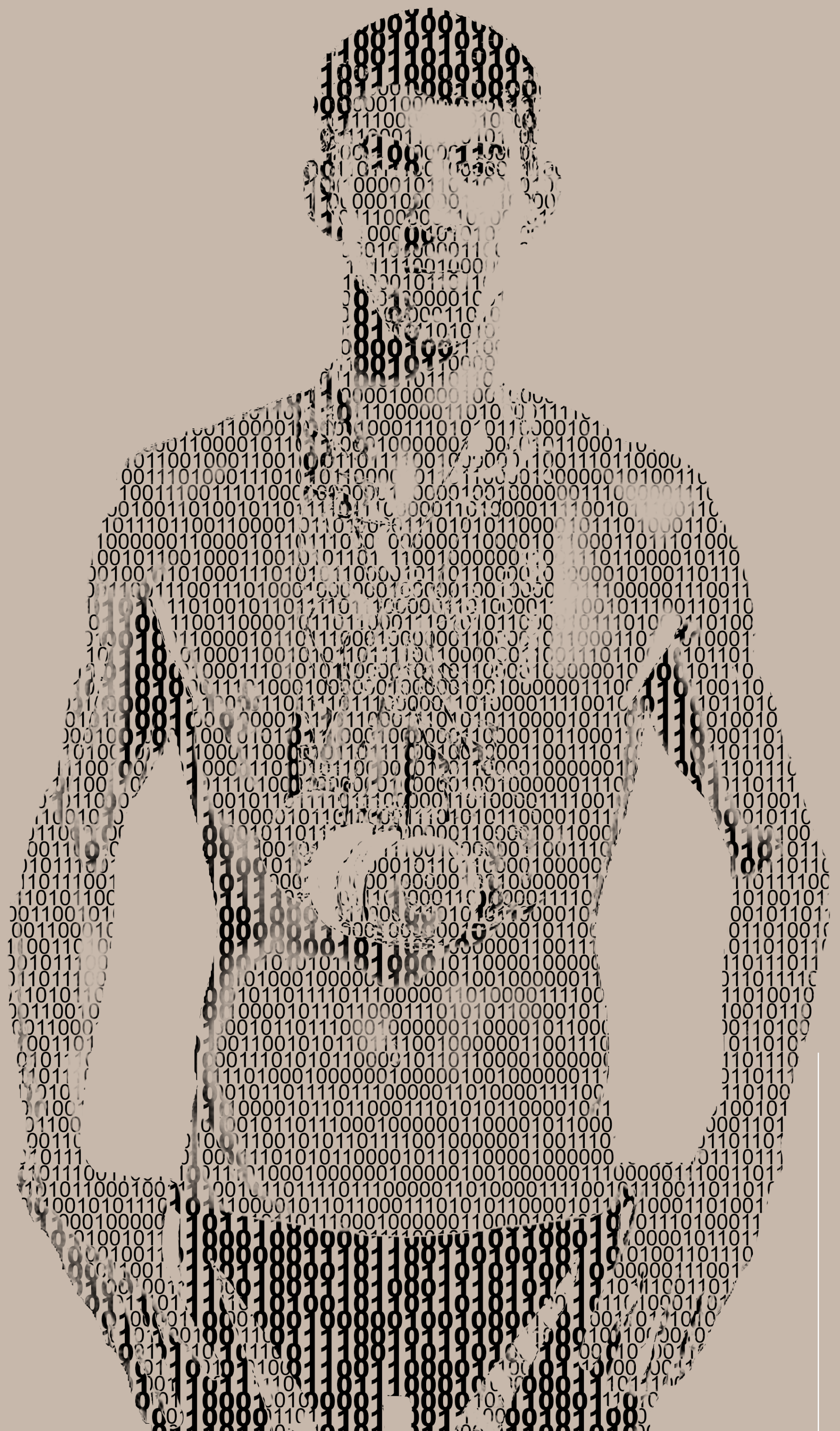

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Virtual Swimming

A psycho-biophysical evaluation of an active video game.

Pooya Soltani

Porto, 2016

UNIVERSITY OF PORTO
FACULTY OF SPORT

CENTRE OF RESEARCH EDUCATION INNOVATION & INTERVENTION IN SPORT
CIFI2D

PORTO BIOMECHANICS LABORATORY
LABIOMEP

Virtual Swimming: A psycho-biophysical evaluation of an active video game.

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KEYWORDS: SWIMMING, EXERGAME, BIOMECHANICS, PHYSIOLOGY, PSYCHOLOGY

Dedication

برای تو، بابا

Statement of Originality

I hereby certify that all of the work described in this thesis is the original work of the author. Any published (or unpublished) ideas, techniques, or both from the work of others are fully acknowledged by the standard referencing practices.

Pooya Soltani
[Signature is available in the printed version]
December 2016

Ethical Disclaimer

Ethical approval for the studies mentioned in this thesis has been granted by the Ethics Committee of Faculty of Sport, University of Porto (Process number: CEFADE 01/2013; Appendix IV.13).

All subjects who participated in the studies of this thesis were free from any physical impairment and signed an electronic consent form. For children, this consent form was obtained from their parents or legal guardian. All participants were fully informed about the nature and objectives of the studies.

Abstract

After the successful introduction of active video games (exergames), it is not clear whether they can be used as educational, training, and motivational tools for physical activity and real sports. We are aiming to evaluate the use of a swimming exergame in physical education and sport domains. We measured different biomechanical, physiological, and psychological parameters, to provide an overview of the possible use of these games in physical education and sport.

Firstly, we reviewed the literature on the application of sport exergames in physical education and sport. Secondly, we compared the movement patterns during swimming exergame in players with different gender, game, and real swimming experiences. Thirdly, we measured muscle activation with two gaming velocities and provided activation patterns of swimming exergame. Fourthly, we measured aerobic and anaerobic energy systems contributions and players' activity profiles in swimming exergame. Finally, we evaluated how enjoyment, usability, and game experience of the game can affect players' future intentions to participate in physical activity and real swimming.

Our results show that players who performed the game better were less active and completed the game faster. Muscle activation was higher in fast gaming and players completed different phases of the arm cycle faster. Anaerobic energy pathway accounted for approximately 9% of total energy expenditure and players were active about 57% of total time of game play. This sport exergame earned a high usability score but did not encourage players to be more physically active. However, it increased players' intentions to participate in real swimming.

We provided robust interdisciplinary tools and evaluation methods to assess exergame performance. This study suggests that the device may not detect complex movements of real swimming and previous knowledge of real swimming may not transfer into better performance. Both aerobic and anaerobic energy systems should be considered in exergame evaluation. Moreover, interactions of physical exertion, platform usability, and players' skill levels should be considered for effective interventions for increasing physical activity.

KEYWORDS: SWIMMING, EXERGAME, BIOMECHANICS, PHYSIOLOGY, PSYCHOLOGY.

Resumo

Após a introdução bem-sucedida de vídeo jogos ativos (exergames), não é claro que os *exergames* possam ser usados como ferramenta educacional, de treino ou motivacional para a atividade física e desporto reais. O objetivo é a avaliação do uso de um *exergame* de natação no domínio da Educação Física e Desporto. Foram medidos diversos parâmetros biomecânicos, fisiológicos e psicológicos, de modo a fornecer uma visão geral do possível uso destes jogos na Educação Física e na prática desportiva.

Em primeiro lugar, foi efetuada uma revisão da literatura sobre a aplicação de *exergames* desportivos na Educação Física e Desporto. Em segundo lugar, foram comparados os padrões de movimento durante a realização do *exergame* de natação em jogadores de diferentes géneros, níveis de experiência de jogo e de prática de natação real. Em terceiro lugar, foi medida a ativação muscular em duas velocidades de jogo e foram disponibilizados padrões de ativação da natação em *exergame*. Em quarto lugar, foram avaliadas as contribuições dos sistemas de energia aeróbio e anaeróbio e os perfis de atividade dos jogadores. Finalmente, foi analisado o modo como a satisfação, a usabilidade e a experiência de jogo podem afetar as futuras intenções dos jogadores de participarem em atividades de natação real.

Os resultados mostram que os jogadores que obtiveram melhor desempenho no jogo foram os menos ativos e os que terminaram o jogo mais rapido. A ativação muscular foi maior nos jogos mais rápidos e os jogadores completaram fases diferentes do ciclo do movimento de braços mais rapidamente. A via energética anaeróbia representa aproximadamente 9% do dispêndio energético total e que os jogadores estiveram ativos durante cerca de 57% do tempo total de jogo. O *exergame* desportivo obteve uma elevada pontuação de usabilidade, mas não incentiva os jogadores a serem fisicamente mais ativos. No entanto, aumentou as intenções de participação em natação real por parte dos jogadores.

Foram fornecidos ferramentas interdisciplinares e métodos de avaliação robustos para a avaliação da realização de *exergames*. O presente estudo sugere que o dispositivo não permite a deteção de movimentos complexos de

natação real e que os conhecimentos prévios da prática real de natação não se traduzem num melhor desempenho no jogo. Tanto os sistemas energéticos aeróbios quanto os anaeróbios devem ser considerados na avaliação de *exergames*. Para além disso, as interações na realização de esforço físico, a usabilidade da plataforma e os níveis de aptidão dos jogadores devem ser tidos em conta no desenvolvimento de uma intervenção eficaz no aumento da atividade física.
PALAVRAS CHAVE: NATAÇÃO, EXERGAME, BIOMECÂNICA, FISIOLOGIA, PSICOLOGIA.

خلاصه

پیشرفت های تکنولوژیک ممکن است سبب کاهش فعالیت بدنی شوند. بعد از ارایه موفقیت آمیز بازی های رایانه ای فعال (بازی-ورزش[1])، از آنها به عنوان ابزار بالقوه در مبارزه با بازی های ویدیویی غیر فعال یاد میشود. مشخص نیست که آیا میتوان از آنها به عنوان ابزاری آموزشی، تمرینی، و تشویقی برای فعالیت بدنی و ورزش واقعی، استفاده کرد.

در این رساله، هدف ما ارزیابی یک بازی-ورزش شنا در شاخه تربیت بدنی و ورزش است. ما پارامترهای مختلف بایومکانیک، فیزیولوژی، و روانشناسی را اندازه گرفتیم تا دید جامعی نسبت به استفاده بالقوه از این بازی ها در تربیت بدنی و ورزش پیدا کنیم. ابتدا، متون مرتبط با استفاده از بازی-ورزش های ورزشی در تربیت بدنی را مرور کردیم. دوما، الگوهای حرکتی بازیکنانی با جنسیت، پیش زمینه بازی و شنای واقعی، را حین بازی-ورزش شنا مقایسه کردیم. سوما، فعالیت ماهیچه ای را با دو سرعت اندازه گرفتیم، و الگوهای فعال سازی را در بازی-ورزش شنا ارایه دادیم. چهارما، مشارکت سیستم انرژی هوازی و غیر هوازی و نمایه فعالیت را حین بازی-ورزش شنا اندازه گرفتیم. در آخر، چگونگی تاثیر لذت، کاربردپذیری[2]، و تجربه بازی را بر مقاصد آینده بازیکنان، برای شرکت در فعالیت بدنی و شنا اندازه گرفتیم.

نتایج ما نشان میدهد که کسانی که اجرای بهتری در بازی داشتند، کمتر فعال بودند و بازی را در زمان کمتری تمام کردند. فعالیت ماهیچه ای در بازی سریع، بیشتر بود و بازیکنان مراحل مختلف چرخه بازویی را سریعتر تمام کردند، که ممکن است ماهیچه ها را به در معرض بیش فعالی و آسیب قرار دهد. ما همچنین نشان دادیم که مسیر انرژی غیر هوازی، تقریبا در ۹٪ کل سوخت انرژی سهیم است، و بازیکنان ۵۷٪ کل زمان بازی، فعال بودند. بازی-ورزش شنا نمره کاربردپذیری بالایی را کسب کرد، اما بازیکنان را به فعالیت بدنی بیشتر تشویق نکرد. با این حال، قصد بازیکنان برای شرکت در شنای واقعی را افزایش داد.

این رساله ابزارهای بین رشته ای برای بهبود بازی شوندگی[3] و اثربخشی بازی-ورزش ها ارایه میدهد. ما روش های ارزیابی قوی را برای اندازه گیری اجرای بازی-ورزش حین یک جلسه بازی ارایه کردیم. این مطالعه نشان میدهد که دستگاه ممکن است حرکت های پیچیده شنای واقعی را تشخیص ندهد، و دانش قبلی شنای واقعی، ممکن است به عملکرد بهتر منجر نشود. با وجود سهم انرژی کمتر، هر دو سیستم انرژی هوازی و غیر هوازی، هنگام ارزیابی بازی-ورزش ها، باید در نظر گرفته شود. همچنین، تعامل فعالیت بدنی، کاربردپذیری دستگاه، و سطوح مهارتی بازیکنان، برای ایجاد یک مداخله اثربخش برای افزایش فعالیت بدنی، باید مد نظر قرار گیرد.

کلید واژه ها: شنا، بازی-ورزش ، بایومکانیک، فیزیولوژی ، روانشناسی.

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[1] Exergame

[2] Usability

[3] Playability

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Porto; December 22nd, 2016

Pooya Soltani

List of Publications

This doctoral thesis is based on the following scientific materials:

Journals

1- Soltani, P., Figueiredo, P., & Vilas-Boas, J. P. (2016). *Does swimming exergame encourage players to participate in physical activity and real sport?.* Manuscript submitted for publication.

2- Soltani, P., Figueiredo, P., Ribeiro, J., Fernandes, R. J., & Vilas-Boas, J. P. (2017). Energy systems contributions and time-motion analysis of swimming exergame. *Scientific Reports,* 7, 5247. doi:10.1038/s41598-017-05583-8

3- Soltani, P., Figueiredo, P., Fernandes, R. J., & Vilas-Boas, J. P. (2016). *Muscle activation and coordination patterns during swimming exergame.* Manuscript submitted for publication.

4- Soltani, P., Figueiredo, P., Fernandes, R. J., & Vilas-Boas, J. P. (2016). Do player performance, real sport experience, and gender affect movement patterns during equivalent exergame?. *Computers in Human Behavior*, 63, 1-8. doi:10.1016/j.chb.2016.05.009

Book Chapters

1- Soltani, P., Vilas-Boas, J. P. (2018). Sport exergames for physical education and training. In M. Khosrow-Pour, D.B.A. (Ed.), *Encyclopedia of Information Science and Technology, Fourth Edition* (pp. 7358-7367). Hershey, PA: IGI Global. doi:10.4018/978-1-5225-2255-3.ch640

2- Soltani, P., Vilas-Boas, J. P. (2016). Muscle activation during exergame playing. In D. Novak, B. Tulu, & H. Brendryen. (eds.), *Holistic Perspectives in Gamification for Clinical Practice.* Hershey, PA: IGI Global. doi:10.4018/978-1-4666-9522-1.ch015

Conferences

I- Soltani, P., & Vilas-Boas, J. P. (2013, October). Exploring learning effects during virtual swimming using biomechanical analysis (a work in progress). In P. Escudeiro, & C. V. de Cravalho. (Eds.), *Proceedings of the 7th European Conference on Games Based Learning* (pp. 793-796). Sonning Common, UK: Academic Conferences and Publishing International.

II- Soltani, P., Figueiredo, P., Fernandes, R., Fonseca, P., Vilas-Boas, J. P. (2014). Muscle activation during swimming exergame. In B. Mason (Ed.), *Book of Proceedings of the XII International Symposium on Biomechanics and Medicine in Swimming* (pp 248-252). Canberra, Australia: Australian Institute of Sport.

II- Soltani, P., Figueiredo, P., Mehrabi, A., & Vilas-Boas, J. P. (2014). Exergame playing in novice and experienced children: A pilot study. *Journal of Physical Activity and Health, 11*(s1) (2014 Global Summit on the Physical Activity of Children: Abstracts), S188. doi:10.1123/jpah.2014-0173

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List of Abbreviations

%	Percent
º	Degrees
x	Multiplied
<	Smaller than
>	Greater than
3D	Three-dimensional
BB	*Biceps Brachii*
ANOVA	Analysis of variance
AVG	Active video game
ACSM	American College of Sports Medicine
BMI	Body mass index
bpm	Beats per minute
b x b	Breath by breath
CDC	Centers for Disease Control and Prevention
cf.	Confer
CI	Confidence interval
°C	Degrees Celsius
DDR	Dance Dance Revolution
d	Cohen’s effect size
ECG	Electrocardiography
EE	Energy expenditure
e.g.	*exempli gratiā* (for example)
EMG	Electromyography
ES	*Erector Spinae*
ESA	Entertainment Software Association
et al.	*et alii* (and others)
GPS	Global positioning system
HR	Heart rate
Hz	Hertz
IBM	International Business Machine Corporation
i.e.	*id est* (it is)

Inc.	Incorporated
IR	Infrared
$[La^-]$	Blood lactate concentration
LABIOMEP	Porto biomechanics laboratory
LD	*Latissimus Dorsi*
LED	Light-emitting diode
MANOVA	Multivariate analysis of variance
min	Minute
MET	Metabolic equivalent for task
MVIC	Maximum voluntary isometric contraction
n	Number
O_2	Oxygen
OMNI	OMNI scale of perceived exertion
PA	Physical activity
PACES	Physical activity enjoyment scale
PE	Physical education
Ph.D.	Doctor of philosophy
PinA	Physical inactivity
r	Effect size
ROM	Range of motion
RMS	Root mean square
RPE	Rate of perceived exertion
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
TB	*Triceps Brachii*
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_2peak$	Peak oxygen uptake
vs.	Versus
UT	*Upper Trapezius*
UX	User experience
WHO	World Health Organization
Wii	Nintendo Wii

x	Horizontal axis
y	Vertical axis
Yr	Year
z	Lateral axis

Terms are written in full when first mentioned and subsequently abbreviated for the remainder of the thesis.

Glossary of Terminology

The information provided in this glossary of terminology refers to frequent terms used in this manuscript.

Avatar: A virtual image of the players presented in a cartoon format.

Electromyography: Analysis of the electrical activity of muscle tissue.

Energy expenditure: Calories used to maintain the body's basal metabolic needs as well as thermogenesis, growth, and physical activity.

Exergame: An active video game that requires degrees of physical exertion to be played.

Maximal voluntary isometric contraction (MVIC): The ability to produce a maximal voluntary effort during an isometric contraction for a muscle group.

Physical activity: Any bodily movement that is produced by contraction of muscles and that substantially increases the use of energy.

Rate of perceived exertion: A subjective psychological scale of physical exertion which participants use to report their exertion levels.

Physical activity: Any bodily movement that increases energy expenditure.

$\dot{V}O_2$: The amount of oxygen consumed per minute (also commonly expressed by the unit of body weight) by an individual while performing an activity.

XBOX 360 and Kinect: An interactive exergame system that captures body movements (using the Kinect sensor) in real time.

General Introduction

This chapter presents an overview of the research, problems, and structure of the thesis. Firstly, we introduced the benefits of PA, described the importance and risks of physical inactivity, and the role of video games. Following that, we addressed the concerns by introducing exergames, their types and genres, and their benefits. Afterward, we set out the research justifications and the necessity of exergame evaluation for utilizing in other serious purposes, injury prevention, and meaningful game play. Finally, we described the thesis structure at the end of the chapter.

Physical Activity Benefits

Any body movements that are created by skeletal muscles and causes energy expenditure (EE) more than what occurs during daily activities are called physical activity – PA (USDHHS, 2008). The benefits of PA are subject to intensity, duration, and frequency of the activity, but even short bouts of moderate-intensity exercise have positive effects on the organism (Tomporowski, 2003). PA contributes to a healthy body weight in children and adolescents (Must & Tybor, 2005), and is associated with lower risks of obesity, insulin resistance, and mental health problems (Blair et al., 1992). Regular exercise and PA elevates the mood, reduces stress, and lessens anxiety sensitivity (Otto & Smites, 2011). Previous research also shows a positive relationship between aerobic fitness and cognitive health (Chaddock et al., 2010), and academic achievements (Castelli et al., 2007; Spitzer & Hollmann, 2013). Moreover, PA has been positively related to motor skills and cardio-metabolic profiles (Wrotniak et al., 2006; Stamatakis et al., 2015; Ekelund et al., 2012). Increasing PA and reducing sedentary behaviors have social, intellectual, and emotional effects (Australia Department of Health, 2014), and health initiatives have provided several PA guidelines for different age groups.

Physical Inactivity

Physical inactivity (PinA) is described as not meeting any of these three criteria: 30 minutes (min) of moderate-intensity PA on at least five days a week, 20 min of vigorous-intensity PA on at least three days a week, or an equivalent combination achieving less than 600 metabolic equivalents (MET) min.week^{-1} (Hagströmer, Oja, & Sjöström, 2006; WHO, 2011). Although PA benefits are documented extensively, the majority of the populations of Western countries do not follow these guidelines. For example, only 14% of Portuguese adults participate in moderate-intensity PA (WHO, 2014). By creating jobs that require less energy, the industrial revolution marked the onset of technological changes (Lieberman, 2013) which had an adverse impact on peoples' PA levels. Leisure-time PA also decreased in the recent years (USDHHS, 2008) due to the transfer of technology into peoples' leisure activities. There are also no recommendations for adults' screen-based entertainment (i.e. watching television, browsing the internet, and playing video games, etc.) which occupies almost half of their leisure time (USDL, 2015; Foley & Maddison, 2010). The fact that players value these activities is the reason why PA interventions aiming to reduce sedentary times are constantly challenged.

Although newer technologies are meant to improve health, they arguably had some negative effects on health, namely by reducing opportunities for PA participation (Parker & Thorson, 2008) and by shifting leisure activities from more physically active ones to more sedentary behaviors (Hill & Peters, 1998; Ford et al., 2005). Environmental barriers such as not having accessible sport facilities and exercise programs (Sallis et al., 2000), neighborhood safety (Molnar et al., 2004), lack of enjoyment (Daniels et al., 2005), lower socio-economic status, and being an ethnical minority are other contributors in increasing sedentariness (Brodersen et al., 2007; Fakhouri et al., 2013). Lee et al. (2009) mentioned that although people are aware of benefits and dangers of PinA, they often mention feelings of discomfort and self-ambivalence as reasons not to exercise. Such feelings were also found to be one of the causes overweight children stop exercising (de Bourdeaudhuij & Deforche, 2001).

Longitudinal studies have shown that sedentary times increase the risk of being overweight and obese in children and adults (Kimbro et al., 2011; Shuval et al., 2013). PinA is a major challenge, leading to causes of death, including heart disease, stroke, cancer, and diabetes (CDC, 2008). Over the past years, the prevalence of obesity has increased significantly, which makes the obese youth prone to greater risk for adult obesity (Ogden et al., 2012; Guo et al., 1994), as well as hypertension, diabetes mellitus, sleep apnea, and orthopedic problems (Dietz, 1998). Many children may also lose interest in traditional forms of PA, leading to higher drop-out rates during adolescents (Slater & Tiggemann, 2010). Being overweight and obese might also result in psychological challenges such as behavioral instability and low self-esteem (Lee et al., 2009), that might reinforce PinA.

Role of Video Games

Screen time activities are done in front of a screen and require a very little EE (Kaneshiro, 2013), and video games are probably the most pervasive forms of screen-based entertainment for today's children and young adults (Staiano & Calvert, 2011). More than 60% of adolescents play video games for an average of 73 $min.day^{-1}$ (Rideout et al., 2010). By providing enjoyment, exciting, and competitive experiences (Thin, 2010), video games are considered as one of the fastest growing forms of recreation (Wang, Khoo, Liu, & Divaharan, 2008). Positive changes in mood (Kirk et al., 2013; Gerling et al., 2012), enhancing socialization (Gerling et al., 2011), and improved quality of life (Rosenberg et al., 2010) are among benefits of computer games. They may also improve players' reaction times, attention allocation, visual attention, task switching, and hand-eye coordination (Granic, Lobel, & Ebgels, 2014; Latham et al., 2013). Video games can be used for training brain (Kato, 2010), strategic thinking, and problem-solving. By enhancing competence and elevation of self-esteem (Ryan et al., 2006), sport video games might also be a predictor of future participation in real-life sports (Adachi & Willoughby, 2014).

On the other hand, excessive use of technology (including video gaming), is suggested to be a contributing factor in obesity (Lamboglia et al., 2013). Too much screen-based activities might reduce the amount of time exercising, and contributes to unhealthy eating habits, such as snacking (Dietz & Gortmaker, 1985), sleep disorders (Healthy Kids, 2015), attention problems, depression, and anxiety. Playing video games are independently and additionally, associated with negative health outcomes (Danielsen et al., 2011; Tremblay et al., 2011). Previous psychological research and content analysis of video games were concerned about violence, the role of gender, and have linked aggression with video gaming (Dietz, 1998; Lee & Peng, 2006; Anderson et al., 2010).

Addressing Concerns

Reducing screen-based activities may not significantly affect PA levels (Rideout et al., 2010), and diet and PA behavior still play more important roles in obesity prevention (Koplan et al., 2005). However, strategies to encourage players to participate in more PA are valuable. As desire and psychological parameters play significant roles in continued PA participation (Poehlman et al., 2000), adolescents may use different opportunities to gain similar benefits with different physically demanding activities. Technology may also offer practical non-traditional PA interventions for encouraging people to adopt healthy behaviors and counter PinA trends. Moreover, results show that adolescents seem to be more responsive to the technology-based programs which may provide more adherence and acceptability in self-monitoring and behavioral change (Shapiro et al., 2008). With the majority of households having access to video games consoles, the challenge is to shift players' participation from sedentary to more active video gaming systems.

Exergames

The concept of active video games (AVG), or exergames, was introduced that keeps certain elements of digital games and tries to solve the problems caused by digital gaming. The term "exergame" refers to digital games in which players have to do some degrees of PA to advance within the game. The technological elements of exergames include sensors, logic processors, and actuators. Sensors obtain information from the players, using cameras and touch sensitive surfaces. The logic processors gather information from sensors, process them, and decide about the feedback to be given to players. Actuators include projectors, audio, and visual devices, and provide feedback to the players. This technology ranges from interactive toys to full interactive installations (Bekker, Hopma, & Sturm, 2010; Poppe et al., 2014), and players' body movements play a vital role in game experience (Mueller, Agamanolis, & Picard, 2003). It is estimated that 25-40% of children play exergames (Wethington et al., 2009; O'Loughlin et al., 2012) which contribute approximately to 45 min of moderate intensity PA per week in women (Kakinami et al., 2015). Some of these games are also specifically designed to enhance sports training experiences (Kajastila & Hamalainen, 2015; Jensen et al., 2015).

Exergames types include auditory, ubiquitous, social, casual, and distributed (Ketcheson, 2016). Auditory exergames are usually used to help people with visual impairment to participate in more PA. Ubiquitous exergames are played over large areas that use global positioning system (GPS) technology. In running exergames, players control the speed of each other by physically running (e.g. on a treadmill) to complete the game's obstacles. In social exergames, players collaborate with each other by social interaction. Casual exergames can be learned easily and use motivating mechanics to exercise at moderate intensity levels, and in distributed exergames, multiple players can participate in the game play over a network. Commercial exergames include Konami's Dance Dance Revolution – DDR (Konami, 1998), a dance pad in which players have to tap buttons with their feet in time with the music. Nintendo Wii consists of Wii Remote (Wiimote), an accelerometer-based handheld controller that players use to mimic the actions provided in the games (e.g. swinging horizontally while playing tennis). Nintendo later released Wii Balance Board, a weight sensing force platform that was developed in conjunction with the game Wii Fit, offering traditional exercise activities. The release of Wii drew new gaming audiences by attracting older users to use motion-based games.

Another common sensor is Microsoft Kinect for Xbox 360 and Xbox One, and can detect the position and movement patterns of players. Kinect version one was introduced in 2010 and incorporates an infrared (IR) laser emitter, an IR depth sensor, a color camera, one light emitting diode (LED), and a microphone array. The sensor can detect whole-body movements in three-dimensional (3D) space, and the user does not have to hold any other controllers. The location of each part is shown in Figure 1.1. IR emitter and IR depth sensor work simultaneously to capture depth data. IR emitter sends infrared light in a "pseudorandom dot” pattern to the objects in front of Kinect. IR depth sensor later measured the distance from which the IR dots are reflected back. Once the calculations are done for all dots, it is possible to construct a 3D space (Zhang, 2012).

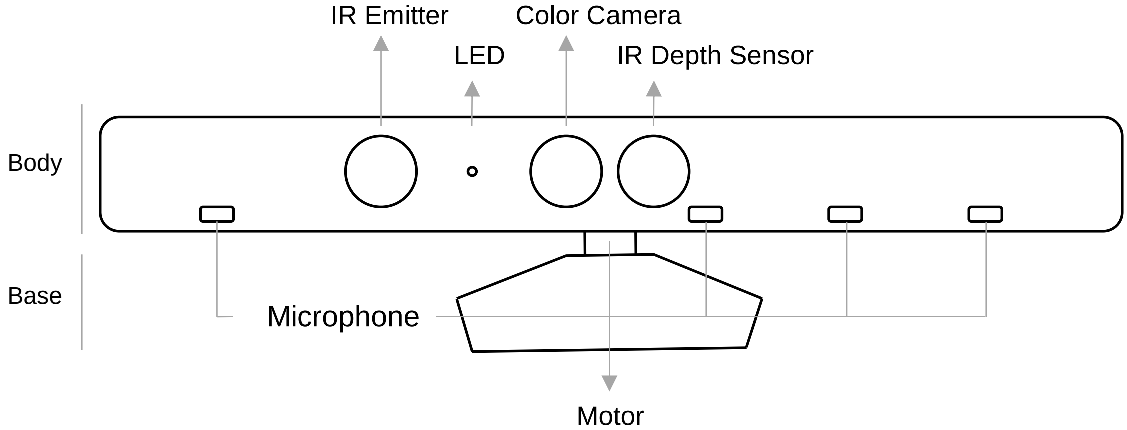

Figure 1.1. Different parts of Kinect sensor.

Allowing players to use their body movements as means of interaction, is the major benefit of exergame that might be part of the solution in combating obesity (Quennerstedt et al., 2014; Gao, Zhang, & Stodden, 2013). By increasing oxygen uptake ($\dot{V}O_2$) and heart rate (HR) compared to television watching, sedentary game play, and unstructured outdoor play (Lanningham-Foster et al., 2006; Biddiss et al., 2010; Peng et al., 2011; MacArthur et al., 2014), exergames provide higher levels of EE (Gao et al., 2015; White et al., 2011), while being perceived as enjoyable and fun (LeBlanc et al., 2013). Additionally, games that incorporate full body movements provide higher levels of exertions (Peng, Crouse, & Lin, 2013), compared to those that use only lower body movements (Biddiss & Irwin, 2010). Besides physiological benefits, improved cognitive engagement (Sun, 2015), motor skills (Fery & Ponserre, 2001), problem-solving skills (Ko, 2002), self-efficacy and social support (Gao & Chen, 2014; Goran & Reynolds, 2005), are common psychological outcomes associated with exergaming. Papastergiou (2009) also argued that exergames may improve young people’s knowledge, skills, attitudes, and behaviors in relation to health and fitness. Virtual reality and exergames could also be used to enhance attentional distraction in overweight participants while having similar physical perceived exertion, to encourage them to continue doing PA (Banos et al., 2016). Players who lack the motivation to join recreational or schedule sport program may also benefit similarly through such physically demanding activities.

Besides exergame benefits, the bigger picture is not just that video games are finding a new audience, but also that they are reconnecting with an audience that had not been considered previously. Elderly population health trends have received attention due to increasing costs of long-term care and medication. Aging is associated with many physical challenges that might reduce older adults' PA opportunities (Deci, 2008). Many of these challenges could be addressed using computer games (Belchior et al., 2013; Fereday & Muir-Cochrane, 2006) and pervasive technology interventions have been utilized to encourage elderly to do PA (Fan et al., 2012). Previous research shows that in both genders, competition and challenge are the primary motivators for game play (Greenberg et al., 2010). However, female exergamers usually exert more during game play, and therefore, exergaming might be a preferable way to integrate PA into their daily routines (Kakinami et al., 2015).

With the growth of gaming industry, developers are trying to reach a broader audience and are looking to apply their talents to areas other than entertainment. This has led to designing "serious games," specific types of games that aim not only to entertain but also serve to educate and change behaviors (Desmet at al., 2014). These applied video games are replications of real-world activities designed to increase motivation and change human behavior while being entertaining (de Boer et al., 2016). These games still have challenging goals, are fun to play, incorporate scoring concepts, and provide skill, knowledge, or attitude that can be utilized in the real world. The categories of serious games are not universal standards, and the sports game genres usually mimic traditional sports, such as tennis and swimming. If sport exergames are capable of improving motor skills necessary to engage in real-life sports, they might potentially facilitate familiarity of a sport by developing mental models (Donaldson & Ronan, 2006; Slutzky & Simpkins, 2009). Moreover, according to expectancy-value model, when higher values are placed on a PA (e.g. swimming), and cost (discomfort) are reduced, participants are more likely to engage in that activity regularly (Gu et al., 2014).

Purpose and Justification

To maximize the effectiveness of sport exergames, to use them for teaching and training sports, to optimize attractiveness of the games, to encourage players to use the games more, and to reap the health benefits, exergames should be evaluated holistically. For an effective serious game development, it is also necessary to involve all partners in benefit (users, educators, researchers, game designers, etc.). Given their purposes, serious games should provide quality content, and their design should be strongly based on proper scientific foundation (Winn, 2008).

Although self-determination theory suggests that for engaging game play, autonomy (or freedom of making as many bodily movements as they want) is necessary during exergaming (Rigby & Ryan, 2011), in sport video games, alternative movements are often discouraged. This conflict provides key challenges for designing exergames for more serious purposes. With increased interest in serious games, guidelines were also provided to help developers for designing games (Djaouti et al., 2011; Isbister, Flanagan, & Hash, 2010). However, many of them are focused on cognitive learning aspects, and therefore, characterizing exergames from different aspects seem to be necessary. Being widely available to consumers and a commercial success (Nintendo, 2016), research on exergames started mostly with the introduction of the Nintendo Wii in 2006. Several methods can be used for monitoring exergame performance that can reflect relative exertion of players. Results can be used to balance between a low-intensity exergame to something that can physiologically benefit players. Since human structure and function varies, this diversity should also be considered while designing exergames.

Researchers are seeking ideas to educate, train, and inspire players using video games. Although in many exergames, education is not the main purpose, they are frequently used as teaching aids in schools as means of modern physical training tools (Vander Schee & Boyles, 2010). Exploration of arguments for using or not using exergames at schools shows that the idea of playing exergames in physical education (PE) is to lessen the growing problems of obesity. By applying exergames in PE curricula, both increased EE and enjoyable PA might be achieved (Quennerstedt et al., 2013). Games can enhance learning (Bergen, 2009) and exergames might support special educational needs. Many exergames such as DDR or Kinect Sports require rapid hand/foot-eye coordination, and thus, they may improve general coordination skills. If exergames could transfer similar sport skills, they might be potentially used as training devices, and might benefit physical, social, and cognitive developments (Staiano & Calvert, 2011).

Understanding the motion of the human body has been an enduring interest and concern within educational settings. With recent developments in technology, not only we have more ways to capture, measure, and interpret body movements, but also a broader scope of potential application areas for the educational domains. Game sensors are used to gather information about how participants play the games. For example, Kinect sensor creates a 3D map of objects and players within its field of view and can capture kinematic data with players' movements (Clark et al., 2012). This information is also displayed on the screen in forms of avatars within the games and can provide real-time visual and performance-related feedback. Game characteristics, game levels, and experience with the games might influence movement patterns while exergaming (Skjæret-Maroni et al., 2016), and for specific designs for various purposes and different populations, movements characterizations are crucial (Skjæret et al., 2015). Such evaluations might also facilitate the adhesion and interactions between players and virtual environments (Bastien & Scapin, 1992; Scapin & Bastien, 1997). Additionally, sport game experience enhancement can be achieved by providing engaging and immersive ambients that replicate the real sport activity. Through these mechanisms, possible problems can be identified, and changes can be applied for more meaningful experiences.

By using different methodologies including accelerometer-based wearable devices, remote imaging sensors, and 3D motion tracking, many exergames and PA monitors estimate EE during the activity. Newer methods have also used cameras and hierarchical kinematic models to objectively assess intensity and EE of activities (Yang et al., 2016). These measurements can be recorded throughout the session without interrupting the game play (Nacke, 2015). From their research, Santo, Barkley, Hafen, and Navalta (2016) also concluded that, as players could maintain moderate-intensity PA throughout the continuous game play, these games could potentially replace sedentary gaming. However, although several validation studies evaluated the accuracy of such devices (Bonomi et al., 2010), Tripette et al. (2014) showed that EE is underestimated when accelerometry measurement was used. For goal-directed game design and to acquire certain intensity while exergaming, Böhm, Hartmann, and Böhm (2016) analyzed body segments' movements and concluded that increasing thighs and upper torso movements might lead to higher EE. On the other hand, insufficient physical exertion and players' retention are barriers to exergames (Hagen et al., 2016), which has led to the hesitation of health organizations in applying exergames as PA replacements (Active Healthy Kids Canada, 2014). Therefore, setting proper training loads are important in designing exertion games, especially when players are competing against each other (Hoffmann, Wiemeyer, & Hardy, 2016).

While players might play exergame for enjoyment, social interaction, or health related benefits, safety is a fundamental criterion. Exergame play puts external loads on the player, and the body reacts to these loads (internal loads). Monitoring both external and internal loads provide insights about the effects of playing on the individuals. It should be noted that while exergames provide low to moderate PA levels, due to the exciting and immersive experience some of these games provide, they might put some of the players to over exert and at risk of injury (Ketcheson, 2016). Overuse injuries may be caused by repetitive actions that frequently happen during playing exergames. Therefore, physiological information could be used not only for providing feedback on inputs, but also as a method to regulate the intensity of game play. For example, Schneider (2016) explained the use of nudge feedback to control players' exertion levels during exergames. The effects of any game can be measured by protocols that should be standardized for games and players. Physiological quantification of load includes EE, oxygen uptake ($\dot{V}O_2$), body temperature, blood lactate [La^-], muscle activation, and HR. Continuous registration of these parameters generates information for balancing work and recovery. Although $\dot{V}O_2$ and HR were previously used to measure physiological loads, creating methodologies that incorporate all the energy systems, may provide a more realistic image of the amount of EE spent while exergaming.

Gamification uses game elements to increase the motivation of engaging in non-gaming context (Zhao, Etemad, Arya, & Whitehead, 2016) and might impact motivation of being physically active (Kari, Piippo, Frank, Makkonen, & Moilanen, 2016). By allowing players to personalize the game play, to create strategies, and to modify challenges, their autonomy and choices might be remained elevated for prolonged engagement (Uysal & Yildirim, 2016). However, there should be a balance between the number of choices available to players to avoid frustration. On the other hand, once players understand the mechanisms underlying the games, they might use strategies to dismiss repetitive movements (Maloney et al., 2015). It should also be noted that integration of feedback, challenge, and rewards into exergames requires attention to cognitive and physical aspects (Lyons, 2015).

Understanding game mechanics that increase players' engagement may increase self-awareness, prolong the game play, or encourage them to participate in more PA (Waddell, Sundar, & Auriemma, 2015). For example, it has been shown that gender and experience do not affect the presence in the virtual world (Warden, Stanworth, & Chang, 2016), and enjoyment of exergames may occur independently of game challenges (Mekler, Bopp, Tuch, & Opwis, 2014). Additionally, gender and exercise intentions have little interaction effects (Xu et al., 2016), and players who perform better in the games, experience greater enjoyment, and have higher intentions for future game play (Limperos & Schmierbach, 2016). Additionally, according to health belief model, individuals' tendencies to participate in a health-related behavior (e.g. exercising) is related to perceived benefits and barriers (Becker, 1974). For example, three weeks of exergaming may positively change young adults exercise intentions (Xu et al., 2016), but it may not affect elderly's intentions (Wu, Li, & Theng, 2015). Sport exergames might affect cost-benefit analysis of exercise participation (Xu et al., 2016) and future exergame intentions have also been positively associated with exercise intentions (Li & Lwin, 2016).

Usability deals with effectiveness, efficiency, and satisfaction in a specific context of use (ISO, 1998). Usability analysis of games is important and might ensure players' adherence and engagement to the game based PA (Yáñez-Gómez, Cascado-Caballero, & Sevillano, 2016). Depending on the goal of evaluation, effectiveness and efficiency could be interpreted differently. For example, if the goal of sport exergames is to teach sport movements, the desired effect or effectiveness would be to learn the movements and efficiency would be defined as how fast players learn to perform the movements while minimizing effort, cost, or time. Moreover, if we consider exergames as serious games, we should keep in mind that the participants may not be avid players (e.g. elderly and children). As these players are not familiar with common game languages, they might end up with having a bad experience playing.

We divided the studies of this thesis into two main categories: efficacy and playability. In efficacy, we are interested in how close the sport exergame can be to the real activity, and in playability, we are concerned if playing with the sport exergame is pleasant, enjoyed, and fun. For this matter, we use a holistic approach covering three areas of biomechanics, physiology, and psychology, and we are planning to connect playability and efficacy.

Aims

With the given positive effects of traditional exercise, the aim of this research was to look at sport exergames as possible means for health and education tools. The goal of our study was to characterize different features of exergame playability using a holistic approach incorporating three areas: biomechanics, physiology, and psychology. To prolong game play while keeping the game joyful and safe, we accepted the challenge of using several evaluation methods that enhance the exergame design.

The overall aim of this thesis is to evaluate the use of sport exergames, with a special focus on evaluating the suitability of exergames for PE and sports. The specific aims were as follows:

1- To review the applications of AVGs in PE and sports.

2- To describe upper limb kinematics of movement associated with sport AVG play in healthy adults using motion capture.

3- To determine the effects of velocity on muscle activation during sport AVG play in healthy adults using surface EMG.

4- To quantify EE during a session of swimming AVG in healthy adults using a portable pulmonary gas exchange system and lactate measurement, and to provide time-motion analysis of AVG play.

5- To determine if playing sport AVG encourages participants to engage in more PA and real sport using psychological questionnaires.

Structure of the Thesis

The findings of this doctor of philosophy (Ph.D.) thesis are organized in various chapters explaining different methodologies. Many parts of the text were published as book chapters (including a book chapter in a scientific encyclopedia), scientific journals, and conference proceedings, where every republished material is cited accordingly. The thesis is organized in the following format:

After the first chapter where we outline aims and structure of this thesis, Chapter 2 has given an overlook of the efficacy of using sport exergames in PE and sports domain. Chapter 3 explores the movement patterns of different players in a swimming exergame. Chapter 4 explains the process to measure muscle activation during sport exergaming, and Chapter 5 focuses on the effects of gaming velocity on muscle activation and activation patterns. Chapter 6 outlines and discusses the complete EE measurement and the activity profiles of different players. Chapter 7 reveals the findings of enjoyment, usability, user experience, and future intention of PA and real swimming following exergaming. Chapter 8 provides general discussions of the findings, Chapter 9 offers recommendations for future research, and Chapter 10 mentions the final conclusions of this thesis.

Different studies of this thesis are focused on the use of a swimming exergame for young adults. An overview of study designs is presented in Table 1.1.

Table 1.1. Study design description.

Study	Design	Population	N included
I	Narrative review	Predefined literature search in Google Scholar database (2013-2016).	179
II	Biomechanics study	Healthy college students (Age 25.15±5.28 years).	46
III	Muscle activation study	Healthy male college students (Age 24.2±3.1 yrs).	20
IV	EE study	Healthy college students (Age 23.8±4.4 yrs).	40
V	Usability study	Healthy college students (Age 24.8±4.98 yrs).	80
Pilot I	Biomechanics study	Healthy college students (Age 22-31 yrs).	10
Pilot II	Muscle activation study	Healthy male college students (Age 24.1±3.3 yrs).	10
Pilot III	Activity profiling study	Health children (Age 7-10 yrs).	10

N = Number.

Delimitations

The study was delimited to healthy university students between the ages of 22-31 yrs who did not have histories of musculoskeletal injuries, preventing them from participation in this study. The study was limited to a number of students at one specific university in Portugal. The protocol used Microsoft Xbox 360 and Kinect sensor, and as part of the game, players were exposed to a familiarization period (i.e. watching how to play the game) at the beginning of the game play. They had the option to watch or skip this period. Participants were exposed to natural settings during playing (e.g. minimum researcher presence and equal room temperature and humidity). Metabolic responses of $\dot{V}O_2$ were measured with open circuit spirometry throughout the game play, and HR was measured using a Polar telemetry unit.

Limitations

Despite equal familiarization period for all players, findings might have been affected by different levels of ability and experience of the participants. The choice of swimming exergame might not necessarily reflect the most used and liked exergame of the general population. There was also sampling bias in this study, as the majority of the sample had sport sciences background. Moreover, We used all available subjects to limit this researcher bias. Confounding variables, such as nutrition, was also another limitation. The EMG study was limited to males, which limits generalizability to female players. Participants in the research studies were playing using the default setting, and therefore, inherent spontaneity might have been compromised (e.g. female participants playing using a male game character).

Chapter 2

Sport exergames for physical education

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Abstract
Sports active video games (exergames) are accessible forms of PA which might also be used in PE and sports curriculum. The purpose of this book chapter is to firstly, review some of the relevant applications of sports exergames for inclusion in PE and sports, and secondly, to characterize one of these games (swimming) from different aspects of biomechanics, physiology, and psychology. We compared movement patterns, muscle activation, EE, enjoyment, usability, and game experience in participants with different performing levels (real-swimmers vs. non-swimmers, experienced vs. novice) and gender. Understanding these parameters may help in the development of more realistic sports exergames and meaningful game play and may give PE teachers a better idea of the inclusion of such games in their practice.
Keywords: Virtual sport, swimming, psychology, physiology, biomechanics

Introduction

Insufficient PA is one the main parameters for mortality and obesity is a growing concern in post-industrial countries. A combination of physical exercise and healthy nutrition is essential for decreasing obesity. AVGs (exergames) are becoming popular as ways of motivating people to exercise more. However, it is not clear whether these serious games could also be used in PE and serve as more than mere entertainment. In this chapter, we will examine existing academic literature based on the characteristics of sport exergames that are important in the domain of PE. We also provide a practical example of psycho-biophysical evaluation of a sport exergame to see how close and encouraging these games are, compared to the real sports.

Background

PE and sports are considered to be a crucial part of primary school curriculum around the world which include both physical and educational contents (Lindberg, Seo, & Laine, 2016). Thanks to digital technologies, new learning environments provide opportunities for skill acquisition and socializing, and researchers are now examining the role, efficacy, and opportunities that these environments provide. On the other hand, several reasons including lack of time, lack of skills of PE instructors, and lack of support might reduce the quality and quantity of PE and sports (Lindberg, Seo, & Laine, 2016). Moreover, pedagogy has always tried to innovate teaching, and PE and sports are also emerging regarding integrating technology into regular classes. One exciting area in which technology and education could merge is by using video games that include visual or auditory (or both) stimulus. Video games can be applied to improve attention, executive functions, and reasoning (Neugnot-Cerioli, Gagner, & Beauchamp, 2015). They are also shown to increase several types of intelligence (e.g. visual-spatial and bodily-kinesthetic) while providing a playful-formative experience (del Moral-Pérez, Fernández-García, & Guzmán-Duque, 2015).

On the other hand, previous psychological research has linked aggression with video gaming (Anderson et al., 2010) and content analysis of video games was mainly concerned about violence and role of gender (Lee & Peng, 2006). As the excessive use of technology, which also includes video gaming, is suggested to be a contributing factor in obesity, a new approach has been proposed to include AVGs (exergames) that incorporate motion sensor technology and could be played using whole body movements. While gamification of regular exercise activities (e.g. GPS-based virtual reality zombie run) has been previously reported, AVGs are not frequently used in the context of PE and sports (Lindberg, Seo, & Laine, 2016), and insufficient evidence about efficacy of exergames exist within schools (Norris, Hamer, & Stamatakis, 2016). Previously, Ennis (2013) considered exergames in three categories of recreation (light to moderate intensity), public health (moderate to intensive PA), and educational (to facilitate skills).

Main focus of the article

Motivation/Literacy to Play and Exercise

Several methods are used to increase players' motivation in sporting activities (Keegan, Harwood, Spray, & Lavallee, 2009), and game-based learning and storytelling are the primary ways to provide intrinsic motivation for learning (Laine, Nygren, Dirin, & Suk, 2016). Exergames provide a non-scary environment to develop components of mastering of fundamental movement skills (George, Rohr, & Byrne, 2016). For example, children might improve aiming and catching skills during virtual tennis without the fear of getting hit by the physical ball. In children with sensory dysfunction, exergames are used to increase their learning motivation and to make them more confident in facing various learning challenges (Chuang & Kuo, 2016). By embedding elements of nature, exergames can also provide a sense of connectedness and environmental concern, which might be important for exercising outdoor (Öhman, Öhman, & Sandell, 2016). Wittland, Brauner, & Ziefle (2015) also suggested that accepting serious games for physical fitness, is not dependent on gender, expertise, and gaming habits. However, when used with older adults, “guided hands-on” and “1-on-1” teaching methods might be used to increase their engagement when facing technology (Seides & Mitzner, 2015), because older adults need more time to master the skills necessary to play AVGs (Santamaría-Guzmán, Salicetti-Fonseca, &

Moncada-Jiménez, 2015). Sun (2013) evaluated the effects of exergame in primary school students and showed that PA situational interest decreases over time, but exergame intensity increases. Therefore, strategies to balance the activities should be considered during the game design phase. Many models of evaluations have been created to explore game characteristics from designers and consumers' perspectives (cf. Mildner, Stamer, & Effelsberg, 2015). Gender, age, game type, players' characteristics and personalities are motivators for game play (cf. Jabbar & Felicia, 2015). For example, Shaw, Tourrel, Wunsche, & Lutteroth (2016) showed that considering personality and motivation of players in a virtual training exergame with two modes of competitive and cooperative game play might increase exercise, especially in competitive individuals.

Learning and Skill Acquisition

Digital games have become great tools in knowledge transfer due to fostering intrinsic motivation in players to acquire more knowledge (Mildner, Stamer, & Effelsberg, 2015). Some sports games may be used to simulate the real sports skills; for example, shooting exergames might have a positive skill transfer for increasing hitting scores (Eliöz, Vedat, Küçük, & Karakaş, 2016), and Vernadakis, Papastergiou, Zetou, & Antoniou (2015) showed that exergame-based interventions could improve object control skills in children. Moreover, players' interactions with the game and other players, affect their learning while sports exergaming (Meckbach, Gibbs, Almqvist, & Quennerstedt, 2014). Exergames might also increase PA while developing motor skills among overweight children and adolescents (do Carmo, Goncalves, Batalau, & Palmeira, 2013). Body tracking technologies have also been used as a live correcting tool for free weight exercises (Conner & Poor, 2016), and improved motor skills (balance) after exergaming was observed with higher scores in female players (Norris et al., 2016).

On the other hand, these games may not be as effective as traditional PE and sports instructions for psychomotor development (Pedersen, Cooley, & Cruickshank, 2016). For example, virtual swimming in the air does not replicate the physical fidelity connected with moving water. A previous systematic review also showed that virtual reality applications have the ability to change behavior but have little gain in knowledge (Omaki et al., 2016). While cognitive functions are crucial for the functional autonomy, Monteiro-Junior et al. (2016) showed that a single bout of virtual reality training does not have any effect on cognitive function in older adults. Johnson, Ridgers, Hulteen, Mellecker, & Barnett (2015) also showed that short bouts of exergame playing may not influence perceived and actual ball control skill competence. Previous research also argues that when mastery is achieved, a gradual decrease in performance is expected (Adi-Japha, Karni, Parnes, Loewenschuss, & Vakil, 2016). Therefore, player balancing techniques should be used to provide an equilibrium between enjoyment and skill acquisition for players with different levels of expertise (Vicencio-Moreira, Mandryk, & Gutwin, 2015).

Competition vs. Cooperation

During gamifying traditional sports, researchers and game designer are often challenged to provide a socially-enriching experience without bombarding players with game information (Choi, Oh, Edge, Kim, & Lee, 2016). Characteristics of different players should also be taken into account; for example, Staiano et al. (2012) concluded that in a group of adolescents, competitive players outperform cooperative participants on executive function test. Girls also play exergames mostly for social interaction and rather than competition, and boys play games for intrinsic reasons (O'Loughlin et al., 2012). Online cooperative exergaming can also increase social relatedness in players compared to the time when they play against a computer character (Kooiman & Sheehan, 2015).

Opinion

Previous research suggests that if PE and sports instructors decide to use exergames in their teaching, they should justify why and how they want to apply them, and design strategies for the students to interact with exergames (Gibbs, Quennerstedt, & Larsson, 2016). For example, a meta-analytic review suggests that playing exergames can improve older adults' physical balance, balance confidence, functional mobility, executive function, and processing speed (Zhang & Kaufman, 2015), and coaches may use these ideas to design more effective exercise programs. Exergame inclusion in PE and sports curriculum may also provide additional tools to meet PA standards and to motivate and engage the student in practice (Rudella & Butz, 2015). On the other hand, Hulteen, Johnson, Ridgers, Mellecker, & Barnett (2015) showed that while players had correct skill performance (during table tennis, tennis, and basketball), they also had proper movement during skill assessment, which shows that presence of evaluator may affect the way participants play. According to Kooiman, Sheehan, Wesolek, & Reategui (2016), exergames should not be seen as the primary tool in PE and sports because there are several parameters that expand the activity beyond virtual environments. Using technology in education is mostly affected by teachers' attitudes towards using technology (Albirini, 2006). While Bransford et al. (1999) talked about the four different learning environment as learner-centered, knowledge-centered, assessment centered, and community centered, it is important to decide which area benefits learning new skills in exergames more.

Characterization

In this part of the book chapter, the authors mention studies that were included in the Ph.D. thesis of the first author about characterizing a sport exergame. In the first part, the authors compared movement patterns of forty-six college students, with different performance (novice vs. experienced, and real-swimmers vs. non-swimmers) and gender. Reflective markers were placed over the skin, and the 3D position of each marker was recorded using a motion capture system. Subject played different techniques (100 meters – m each) of a swimming exergame designed for Microsoft Xbox and Kinect (Michael Phelps: Push the Limit, 505 Games, Milan, Italy). Subjects had to stand in front of Kinect and start their game plays by "hyping" for the virtual crowd (Figure 1, Panel A). Then they had to slightly bend forward (mimicking start for the crawl, breaststroke, and butterfly; Figure 1, Panel B). For the backstroke technique, the start is shown in Figure 1, Panel C. Following the "Go!" command, they had to extend their back (Figure 1, Panel D) and swim according to the techniques (Figure 1, Panel E to H for crawl; Panel I for backstroke; Panel J for breaststroke, and panel K for butterfly). To start a new lap, they had to extend their arm forward (Figure 1, Panel L) and continue swimming. For terminating the race, they had to drop both arms (Figure 1, Panel M) and raise one arm immediately (Figure 1, Panel N).

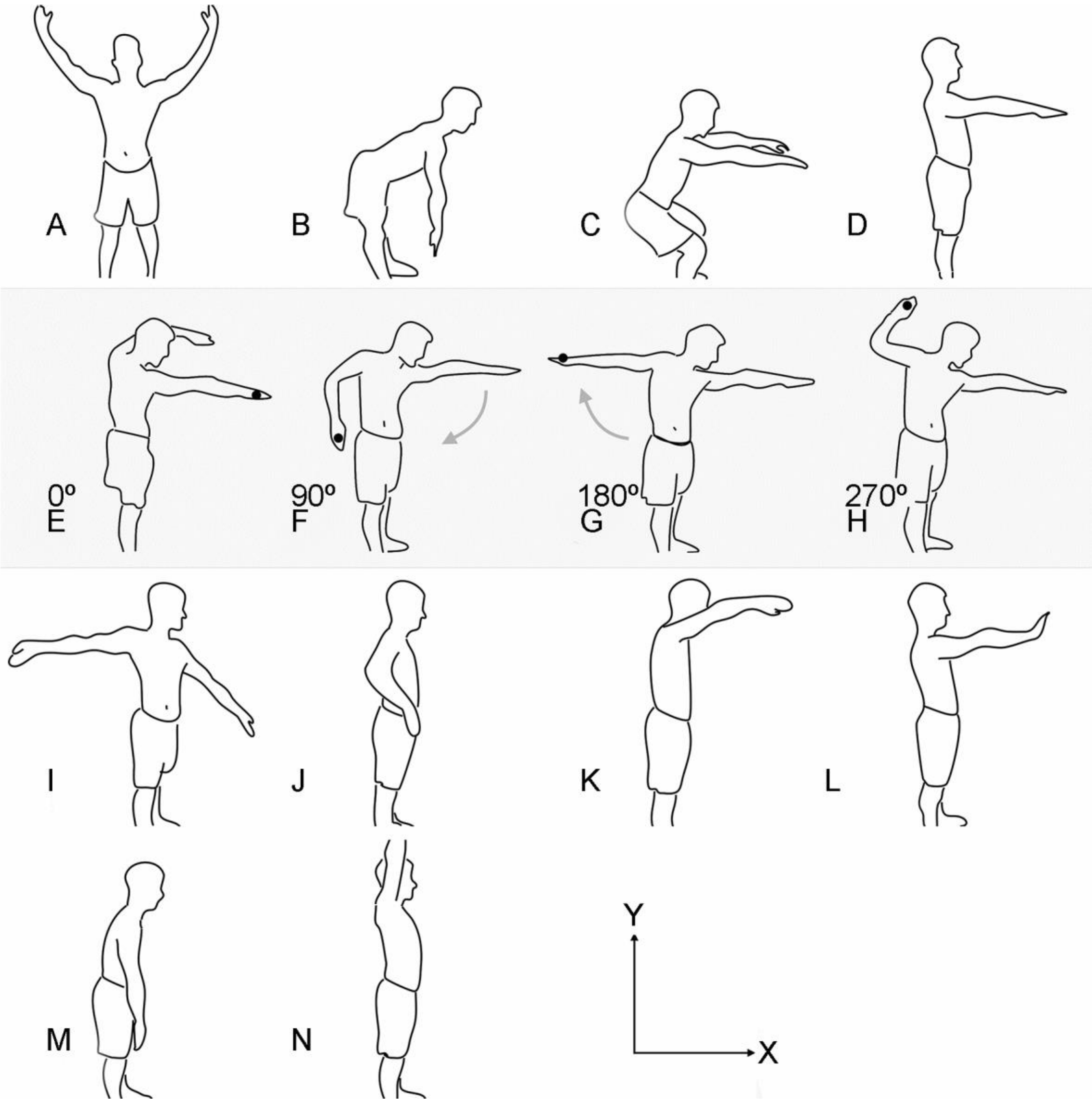

Figure 2.1. Body position during different phases of the game.

The game play was divided into two phases of normal (with on-screen visual feedback to prevent players from playing too fast or too slow) and fast (playing without any feedback). Players' performances were ranked from 1st to 8th. The results showed that players who ranked better in the game (Figure 2), completed the game faster and with fewer arm cycles. By visually inspecting Figure 2, we can see that movement patterns of good performers were different that bad performers, who were mostly real-swimmers, meaning that the game does not encourage players to swim correctly. Moreover, those who had prior experience with the game had fewer arm cycles, and real-swimming experience and gender did not affect biomechanical parameters.

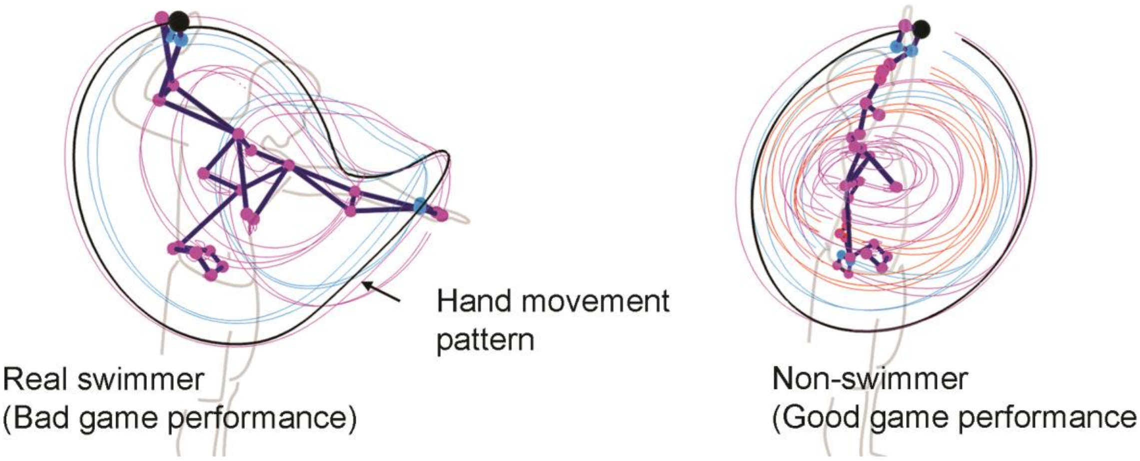

Figure 2.2. Movement patterns during swimming exergame.

In the second study, the authors measured and compared aerobic and anaerobic energy systems contributions and the activity profiles of participants while sport exergaming. Players were equipped with a gas analyzer to measure oxygen uptake, and blood lactate was measured using a small amount of blood from their ear lobe after each technique and following the game play. From these two parameters, we were able to measure the total EE during the game play. Players' game plays were also filmed to measure total playing time (TPT), effective playing time (EPT), resting time (RT) and effort to rest ratio (E:R) using video analysis. Our results showed that anaerobic lactic pathway accounted for around 9% of total EE and EE was not different between performing groups. This shows that although the level of EE is lower compared to real-swimming, both energy systems should be considered when analyzing sports exergames. HR was also measured during the game play, and differences were observed between real-swimmers and non-swimmers in the first technique. This confirms that real-swimmers tend to swim correctly and exert more at the beginning of the game, but as soon as they realized the mechanisms of the game, they tend to exert less. Players were active around 57% of total time, and E:R was approximately 1.3. Our results also show that although players dedicated more time playing than resting, the changes were not different between players. Experienced players had lower TPT, EPT, and E:R compared to their novice counterparts, suggesting that experienced players learn the strategies to play the game with lower exertion. This confirms the necessity of designing games with lower resting times (loading of the game, navigating between the menus, etc.), dedicating more time to the actual game play.

In the third study, the authors measured muscle activation during sport gaming. Surface EMG electrodes were placed over *Biceps Brachii* (BB), *Triceps Brachii* (TB), *Latissimus Dorsi* (LD), *Upper Trapezius* (UT), and *Erector Spinae* (ES) muscles. These muscles were chosen as they are frequently activated during swimming or were relevant because of the game itself. Maximum voluntary isometric contraction (MVIC) of each of the muscle was also measured to normalize the activation in percentages. Our results showed that muscle activation ranged from 5 to 95% MVIC, and differed between normal and fast swimming for all techniques. Muscular coordination was also investigated using biomechanics and observed that when participant plays faster, they complete different stages of the game faster, which results in higher stress some of the muscles more. Measuring muscle activation is important because it can show if players with greater experience, exert and engage less or not. While challenges in sedentary games are usually controlled by adjusting the complexity of mental tasks, employing in-game physical challenges can be unique characteristics of exergame design and muscle activation evaluation can provide guidelines to make sports exergames closer to real activities. Such evaluations can also address the Concerns regarding long-time computer/video game use, repetitive movements, and musculoskeletal disorders, such as neck and shoulder pain. Moreover, although sports exergames may not produce as much muscle activation as the real activity, such activities might still benefit participants to develop muscular endurance, especially when participation in real sport is not possible or practical due to disability, fear, or injury.

In the last study, the authors evaluated the game experience, usability, and enjoyment during sport exergaming to see if they affect future participation if PA, real sport, or both. Enjoyment can both predict and be an outcome of PA participation and is one of the reasons why people play video games. System usability scale (SUS) is a measurement of learning, control, and understanding a game, and higher SUS grade means easier interaction between human, different games and menus, and various controllers and gaming platforms. User experience (UX) deals with consumers' dynamic perceptions and responses of products and systems and is an important factor for game design and positioning of the problems. For measuring enjoyment, a short version of Physical Activity Enjoyment Scale (PACES) questionnaire with two additional questions was used to measure future intentions of participation in PA and real swimming. Game usability was measured by System Usability Scale and playability aspects using Game Experience Questionnaire. Our results showed that Female players with real swimming and exergame experience enjoyed the game more. Usability score was around 75 which is considered as good with high acceptability. PA intentions did not change within performing groups, but swimming intentions were increased for all players. A possible explanation might be that future PA intentions of those who frequently exercise, may not be affected by playing exergames. Another explanation might be that those who do not exercise regularly, may think that the health benefits attained through exergaming are enough, and there is no need for further PA participation. It might be possible that novelty and entertainment elements of swimming exergame, played a role in influencing players' attitudes towards real swimming intention.

Future research direction

In our research, most of the players had sports science background and were physically active, which might have influenced the way they were interacting with the game. The presence of the researchers themselves might have affected players' performance to play differently. It might be possible that novelty and entertainment elements of swimming exergame, played a role in influencing players' attitudes towards real swimming intention and therefore, longitudinal studies should be conducted to check the changes in intentions in the long run.

Conclusion

In general, our data suggest that better performance inside the game does not necessarily mean better performance in real swimming. The motion capture sensor is also not capable of capturing delicate movements of swimming, and it does not encourage players to swim correctly. Therefore, the game may not be used as a training tool for real swimming and may only be used as a motivational tool for teaching basic movements of swimming (e.g. coordination of the upper limbs). While we do not deny the possible role of video games in PE and sports settings, we believe that there is still a long way to use sport exergames in the PE and sports.

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Key terms and definitions

Exergame: A combination of “exercise” and “game” is a term used for video games that are also a form of exercise.

Game-based learning: A type of game play that has defined learning outcomes.

Skill acquisition: A specific form of learning as the representation of information in memory concerning some environmental or cognitive event.

Game User Research: It focuses on players' behavior via techniques such as playtesting, analytics, expert analysis, and others.

Chapter 3

Do player performance, real sport experience, and gender affect movement patterns during equivalent exergame?

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Abstract

This study compared the movement patterns of forty-six college students, playing bouts of swimming exergame, while categorized based on their playing performance, gender, and prior experience of real swimming and exergames. Swimming events were divided into normal (controlled by visual feedback) and fast (no feedback) phases and upper limb kinematics were monitored during front crawl event. Those who performed better completed the game with fewer upper limb cycles and in a shorter time ($p < 0.003$). Prior exergame experience resulted in higher start velocity ($p = 0.019$) and those who were familiarized with this swimming exergame, completed the front crawl event with fewer cycles ($p = 0.022$). Gender and real swimming experience did not affect biomechanical variables. With various playing styles and differences to real swimming movements, the data suggest that the motion capture device is not able to detect complex movements of swimming and previous knowledge of real swimming do not necessarily transfer into better exergame performance. These changes might have happened due to higher adaptation to the exergame. Understanding these patterns may help in the development of more realistic sport exergames and meaningful game play.

Keywords: Research Methods & Experimental Design, Biomechanics, Virtual Sport, Performance, Front Crawl.

Introduction

Despite documented benefits of PA, many people are still living inactive lifestyles. Interventions for decreasing sedentariness for overweight youth typically fail, because of low motivation and high attrition rates (Sardinha et al., 2012; Summerbell et al., 2005). Youth may also stop regular PA during their adolescence, which may lead to weight gain (Slater & Tiggemann, 2010). Moreover, there are some other well-identified contributors to physical inactivity, namely the lack of access to PE and sports at school (Brownson et al., 2009), being a racial/ethnic minority group (Brodersen et al., 2007), having low socioeconomic status (Kristjansdottir & Vilhjálmsson, 2001), and engaging in prolonged television watching (Hu et al., 2003). As part of screen-based activities, video game playing is increasing among youth and has changed significantly from arcade games to accessible video games (Lenhart et al., 2008). However, high exposure to video games has raised psychological and physiological concerns (Roberts et al., 2003), leading to the design of exergames in which players have to interact using their body (requiring some degree of PA). Using Kinect, a low-cost motion capture sensor, players do not have to hold any extra gadgets during the game play and the sensor can detect full body joint segments (Zhang, 2012), providing indoor experiencing many sport-related activities.

According to specificity of training principle, repeating similar movements may provide skilled behavior (Barnett et al., 1973) and, as sport exergames consist of many repetitive movements, they might potentially be helpful or detrimental in improving fundamental movement skills (FMS) which are the basis of more complex and specific sport motor skills (Lubans et al., 2010). It has also been proposed that for an optimal performance between specific activity (real sport) and a repeated task (sport exergame), task constraints should be similar (Newell, 1989). For example, Downs and Oliver (2009), found that putting a golf ball in a Nintendo Wii game, actually led to net gains in the refinement and production of real putting behavior. Such naturally mapped exergame controllers provide an interactive, dynamic, and enjoyable experience and might increase feelings of self-efficacy and learning exercise behavior (Skalski et al., 2011; McGloin et al., 2011). On the other hand, excessive exergame playing may also lead to injuries and conditions such as Wii-shoulder (Cowley & Minnaar, 2008), Wiiitis (Bonis, 2007; Nett et al., 2008), and X-boxitis have been previously recognized by medical doctors. Specific injuries and risks associated with excessive practice are important, especially when players are not completely aware of their bodies and surroundings. Therefore, evaluation of movement patterns is essential for designing exergames and realistic sport games should require movements determining good performance.

Previous research suggests that although exergames require active participation, they are usually less demanding than real-world exercises (Graves et al., 2008). Movements during exergaming are highly different (Levac et al., 2010) and depending on games, consoles, and strategies that different players employ, patterns vary from full body to small wrist movements. For example, it was shown that kinematics of real and virtual tennis differ (Bufton et al., 2014), and experienced real-football players had smaller reaction time and made fewer corrective movements compared to novice players during a virtual football video game (Savelsbergh et al., 2002). Previous research also showed that quantity of movements in experienced exergame players is not different than the ones of novice players (Levac et al., 2010). Moreover, physiological evaluations show that males and females are equally active during exergaming sessions (Sun, 2013), but there are contradictory results regarding time spent playing exergames between the two genders (Sit et al., 2010). While there are non-modifiable challenges during playing sport exergames (e.g. lack of forces from water in swimming exergame or holding a physical racket during tennis), for a more meaningful experience, movement patterns should be as close as possible to real sports. More detailed evaluations are needed to provide evidence for the benefits of sport exergames and, if showing movement behavior similar to real sports, they can potentially be a low-cost tool for increasing PA and skill acquisition. As research investigating the amount of movement and different strategies of playing in exergames is scarce, we have purposed to compare upper limb kinematics in a swimming exergame between players with different game performance, prior real swimming and exergame experience, and gender.

Methods

Participants

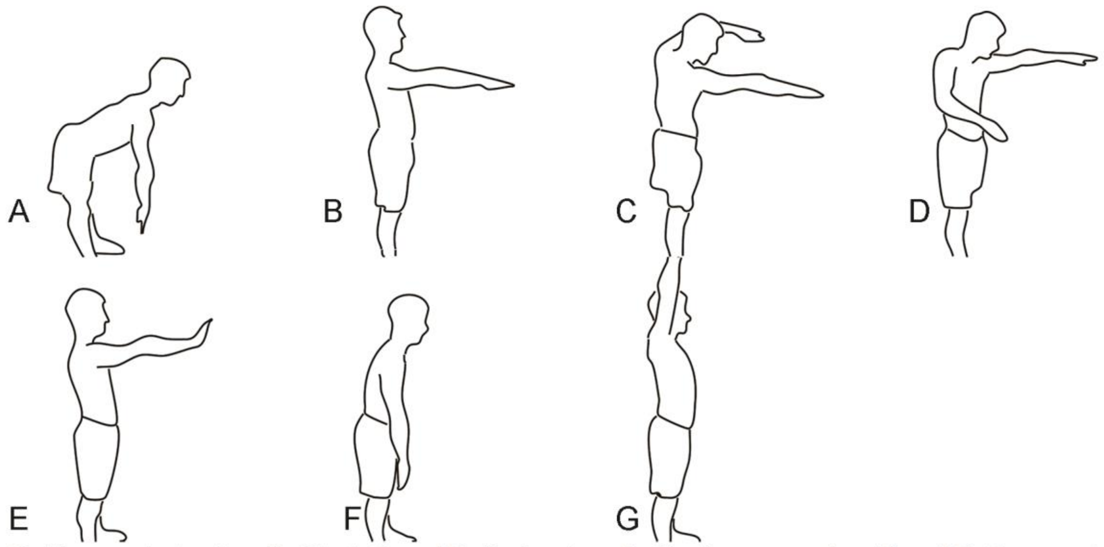
35 male and 11 female college students (mean±SD 24.4±4.4 vs. 27.3±7.2 yrs of age, 1.77±0.07 vs. 1.66±0.06 m of height, and 72.7±10.8 vs. 58.4±7.1 kilograms (kg) of body mass, respectively) were recruited through word of mouth, flyers, and online advertisement. The procedures were approved by the local ethics committee (Process number: CEFADE 01/2013) and, prior to testing, participants signed the informed consent. Data from participants' preferred upper limbs were considered in the analysis.

Procedures

Twenty-two spherical reflective markers of 20 mm were placed on the anatomical landmarks over the skin (cf. Rab et al., 2002): 7th cervical vertebrae, acromioclavicular joints, lateral and medial epicondyles approximating elbow joints, wrist bar thumb side and pinkie side (radial styloid and ulnar styloid), dorsum of the hand just below the head of the second and fifth metacarpal, inferior lower border of scapula bones, sacrum, sternum, anterior-superior, and posterior-superior aspects of iliac crest. The 3D position of each marker was simultaneously recorded at 200 Hertz (Hz) using a 12 camera motion capture system (Qualisys AB, Gothenburg, Sweden) using a specific acquisition software (Qualisys Track Manager, Qualisys AB, Gothenburg, Sweden).

Subjects played different techniques (100 m each) in a swimming exergame designed for Microsoft Xbox and Kinect (Michael Phelps: Push the Limit, 505 Games, Milan, Italy). The game play was divided into two phases (normal and fast), and the upper limb kinematics during front crawl was monitored. Players' performances were ranked from 1st to 8th and categorized as "Good" (1st to 4th) and "Bad" (5th to 8th) in a swimming exergame competition. Players ranked their real swimming and exergame experience from 1 to 5 where 1 was novice and 5 was experienced (including front crawl). If subjects played backstroke, breaststroke, or butterfly techniques before front crawl, we considered them as experienced with the exergame (swimming exergame experience).

During the front crawl event, subjects had to stand in front of the Kinect sensor and bend forward (preparatory position; Figure 3.1, panel A) and, as soon as they saw the visual command, they had to return back to standing position with upper limbs in front (Figure 3.1, panel B). Afterward, subjects had to swing their upper limbs (Figure 3.1, panels C, D, and E) to move the avatar in the game. At the middle of the second lap, there was a possibility to swim as fast as possible called “Push the Limit.” At the end of the event, they had to drop their upper limbs (Figure 3.1, panel F) and then raise one to finish the race (Figure 3.1, panel G). To prevent from too fast or too slow game play, an on-screen visual feedback bar indicated if the speed was at the moderate level.



A: Getting ready to dive; B: Start; C and D: Swimming; E: Starting a new lap; F and G: Termnnating the race.

Figure 3.1. Body position during different phases of the front crawl event.

Data Collection and Analysis

Before each experiment, cameras were calibrated to the measurement volume of 5 m deep by 3 m wide by 3 m high, in front of the Kinect sensor. A 10 s static trial was recorded for each subject while standing in an anatomic position, as the baseline measurements for processing the kinematic data. Subjects were asked to wear bright clothes that neither absorb nor reflect the light that causes gaps in 3D detection/reconstruction (Dutta, 2012). Three consecutive front crawl upper limbs cycles in each phase were considered in the analysis and a 3D motion analysis package (Visual3D, C-Motion, Rockville, MD) was used to compute joint kinematics. The laboratory and segment local coordinate systems were defined as illustrated in Figure 3.2, with the local coordinate system defined at the proximal joint center for each segment. For the elbow, the joint centers were located mid-way between the humeral medial and lateral epicondyles, and for the hand, midway between the markers placed on the second and fifth metacarpals.

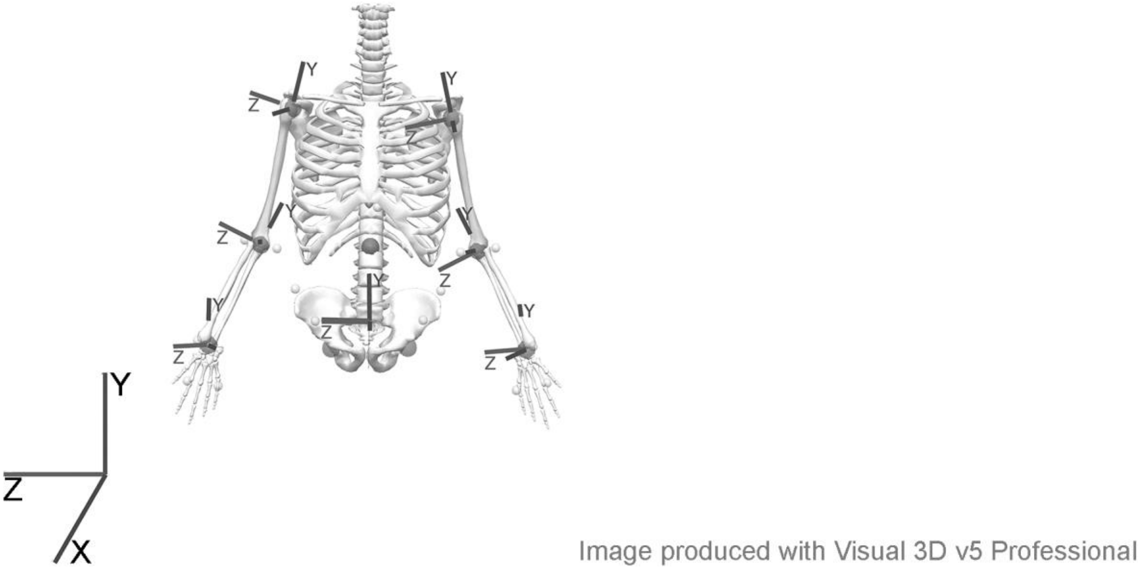


Figure 3.2. Laboratory and segment coordinate systems of the upper body used for processing the kinematic data.

Table 3.1 lists kinematic variables that were measured during the exergame play and demographic and kinematical data were presented as mean±SD and subjects within each performing groups were compared using one-way analysis of variance (ANOVA). Normality and homogeneity of variance were checked and, in the case of abnormal distribution and non-homogeneity, alternative statistics were applied. Outcomes of kinematic variables across performing groups (as between-group variables) were also analyzed using multivariate analysis of variance (MANOVA). The level of significance was set to $\alpha = 0.05$ and IBM Statistical Package for the Social Sciences (SPSS) Statistics 20.0 (Chicago, IL) was used for all statistical analyzes. As a priory and to detect differences between groups, power calculation indicated that at least 32 participants should be included (Faul et al., 2007). Sample size calculation was based on a pilot study testing 10 subjects and determinants for calculation were $\alpha = 0.05$ one-tail, power = 0.70, allocation ratio of 0.7, and effect size of 0.8.

Table 3.1. Description of biomechanical parameters.

Variables	Title (unit)	Description
1	Total time of the event (s)	Measured from the dive in phase until subjects finished the event (Figure 3.1, panels B and G).
2 3	Numbers of cycles – normal (n) Numbers of cycles - fast (n)	Each cycle is defined from the moment when the hand's center is at its maximum X coordinate (Figure 3.1, panel C) until it returns to the same position.
4	Start velocity ($m.s^{-1}$)	Measured by the velocity of the hand from the starting position to the position where the hand's center is at its maximum X coordinate (Figure 3.1, panels A and B).
5 6	Mean velocity - normal ($m.s^{-1}$) Mean velocity - fast ($m.s^{-1}$)	Measured on the hand's center during normal and fast phases.
7	Max velocity - fast ($m.s^{-1}$)	Is defined as maximum velocity during the fast swimming phase.
8	Hand path distance (m)	Measured by the angular distance covered by the hand.
9 10	Max arm depth - normal (cm) Max arm depth - fast (cm)	Was the distance of hand's to the ground (Figure 3.1, panels F and G).
11 12	Max arm height - normal (cm) Max arm height - fast (cm)	Was the distance of hand's to the ground (Figure 3.1, panels F and G).
13 14	Max arm width - normal (cm) Max cycle width - fast (cm)	Measured by the maximum lateral distance of hand's center relative to the shoulder's joint center.
15 16	Elbow angle - normal (°) Elbow angle - fast (°)	Was the angle between the shoulder-to-elbow and the elbow-to-wrist position vectors in both normal and fast phases.
17 18	Trunk rotation - normal (°) Trunk rotation - fast (°)	Was the angle change created by a vector connecting the two shoulders' joint centers and the vector connecting the superior markers of iliac crest in the static trial, projected onto the X,Z plane.

Results

Table 3.2 presents the mean±SD for kinematic variables within performing groups. Although most of the variables were not different between performing groups, participants with good performance completed the event faster (48.45±1.58 vs. 53.31±4.11 s; H(1) = 17.53, $p = 0.001$) and with fewer cycles both in normal (27.67±2.60 vs. 32.77±6.00; H(1) = 8.87, $p = 0.003$) and fast (9.39±1.47 vs. 12.46±3.23; H(1) = 11.45, $p = 0.001$) swimming phases. Subjects with prior exergame experience presented higher start velocity (5.78±1.25 vs. 4.81±1.32 m.s-1; F(1,44) = 5.98, $p = 0.019$) and lowered their hands more during the fast swimming phase (maximum cycle depth – fast; 87.70±17.74 vs. 76.61±10.96 cm; H(1) = 5.02, $p = 0.025$). Participants with previous swimming exergame experience had fewer cycles (total numbers of cycles – normal; 27.46±1.72 vs. 31.25±5.88; H(1) = 5.25, $p = 0.022$) and lowered their hands less during normal phase of swimming (maximum cycle depth – normal; 87.23±13.97 vs. 79.56±15.61; H(1) = 4.29, $p = 0.038$). Prior real swimming experience and gender did not cause differences in kinematical variables ($p > 0.05$). Considering participants' gaming performances, prior real swimming experience, prior exergame experience, gender, and prior swimming exergame experience, all together, there were also no differences in kinematic variables ($p > 0.05$).

Figure 3.3 provides a typical example of movement patterns during front crawl for a player with bad performance and the other with good performance. Despite differences from real sport, it is evident that bad performers were usually playing closer to real swimming, while good performers' movements were enough to win the game.

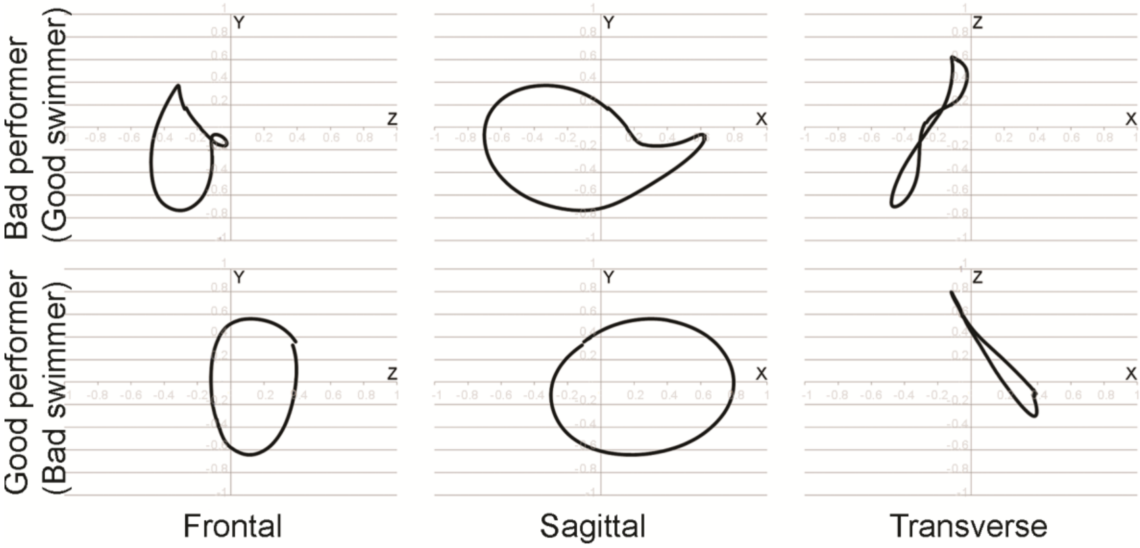


Figure 3.3. Sample movement patterns of preferred hand in one complete cycle of front crawl during exergame playing between a good and bad performance.

Table 3.2. Mean±SD values of kinematic variables during exergame front crawl.

Variables	Exergame Performance		Real Swimming Experience		Exergame Experience		Gender		Swim exergame experience	
	Good (n=33)	Bad (n=13)	Swimr (n=35)	Non-Swimr (n=11)	Exp (n=17)	Novice (n=29)	Male (n=35)	Female (n=11)	Exp (n=26)	Novice (n=20)
1	48.45±1.58 [18.38]*	53.31±4.11 [36.50]	49.97±3.58 [24.24]	49.36±2.50 [21.14]	49.24±1.82 [22.79]	50.17±3.96 [23.91]	49.29±2.69 [22.01]	51.55±4.61 [28.23]	48.81±1.49 [20.56]	51.15±4 .49 [27.33]
2	27.67±2.60 [19.83]*	32.77±6.00 [32.81]	29.20±4.73 [23.21]	28.82±3.57 [24.41]	27.82±1.70 [22.15]	29.86±5.35 [24.29]	28.11±2.82 [21.73]	32.27±6.90 [29.14]	27.46±1.72 [19.56]	31.25±5.88 [28.63]*
3	9.39±1.47 [19.38]*	12.46±3.23 [33.96]	10.23±2.23 [24.21]	10.36±3.35 [21.23]	9.71±1.82 [21.24]	10.59±2.81 [24.83]	9.94±2.04 [22.67]	11.27±3.55 [26.14]	9.50±1.53 [20.42]	11.25±3.16 [27.50]
4	5.35±1.28	4.71±1.51	5.21±1.32	5.02±1.55	5.78±1.25*	4.81±1.32	5.25±1.27	4.90±1.66	5.39±1.17	4.88±1.57
5	2.64±0.66	2.51±0.70	2.65±0.73	2.47±0.42	2.54±0.58	2.64±0.72	2.62±0.71	2.56±0.51	2.60±0.57	2.61±0.79
6	4.17±1.04	3.70±0.92	4.01±1.12	4.10±0.69	3.94±1.19	4.08±0.93	4.08±1.12	3.89±0.64	4.26±1.07	3.75±0.91
7	6.41±1.42	6.12±1.72	6.45±1.62	5.97±0.95	6.18±1.47	6.42±1.53	6.43±1.63	6.01±0.93	6.55±1.54	6.04±1.41
8	117.85±23.67	127.15±37.04	120.51±30	120.36±19.70	117.82±25.99	122.03±29.41	117.91±28.30	128.64±26.49	120.81±24.57	120.05±32.53
9	80.48±12.99 [21.77]	89.03±19.11 [27.88]	82.93±16.16 [23.21]	82.78±12.60 [24.41]	88.75±18.68 [27.94]	79.46±11.90 [20.90]	84.19±16.35 [24.34]	78.77±10.63 [20.82]	79.56±15.61 [19.90]	87.23±13.97 [28.18]*
10	78.50±13.56 [21.73]	86.30±16.50 [28.00]	81.96±15.29 [24.64]	76.74±12.39 [19.86]	87.70±17.74 [29.29]*	76.61±10.96 [20.10]	82.47±16.29 [25.01]	75.10±4.89 [18.68]	78.58±16.00 [20.87]	83.48±12.66 [26.93]
11	172.79±23.02	170.01±16.43	172.40±22.06	170.74±19.20	176.64±24.18	169.29±19.21	174.29±21.90	164.73±17.85	172.48±25.31	171.39±14.93
12	177.05±23.94	170.82±18.56	176.25±23.67	172.23±19.10	180.41±25.79	172.29±20.25	177.26±23.48	169.01±18.77	178.17±25.87	171.55±17.18
13	37.86±10.86	34.65±12.87	36.73±11.78	37.65±10.64	36.40±13.24	37.27±10.44	37.59±12.06	34.92±9.25	37.14±11.27	36.71±11.88
14	40.20±8.54	36.83±12.63	39.20±10.07	39.97±9.50	38.84±10.12	39.48±9.84	38.48±10.74	41.69±5.88	40.01±9.41	38.24±10.53
15	112.97±16.07 [23.85]	110.15±12.57 [22.62]	113.09±14.99 [24.53]	109.27±15.72 [20.23]	113.12±17.89 [23.65]	111.62±13.48 [23.41]	113.34±16.19 [24.33]	108.45±10.61 [20.86]	113.73±16.45 [24.88]	110.15±13.23 [21.70]
16	112.70±15.72	109.38±10.47	111.40±14.28	112.91±15.43	110.76±17.57	112.34±12.49	111.74±15..85	111.82±8.85	112.42±15.93	110.90±12.49
17	39.76±13.63 [24.94]	34.38±17.36 [9.85]	40.17±15.85 [25.39]	32.09±8.58 [17.50]	41.29±15.15 [26.50]	36.45±14.52 [21.74]	39.60±15.47 [24.40]	33.91±11.91 [20.64]	39.35±13.66 [25.19]	36.80±16.37 [21.30]
18	33.61±12.91 [21.89]	38.69±13.23 [27.58]	36.66±13.25 [25.11]	29.91±11.51 [18.36]	36.00±14.90 [24.32]	34.48±12.10 [23.02]	35.46±13.78 [23.56]	33.73±10.93 [23.32]	34.00±11.93 [23.08]	36.40±14.61 [24.05]

Data are presented as mean±SD or [mean rank]; Swimr = Swimmer; Exp = Experienced; n = Number; M = Male; F = Female; Elbow angles were calculated throughout each cycle; *: differences were observed between the two groups within each performing categories.

Discussion

The main purpose of this study was to characterize and compare kinematic variables in a swimming exergame between players with different real-swimming experience, exergame experience, gender, and performance status. Results showed that the performing groups were similar in the majority of kinematic variables and players with better performance completed the game faster and with less effort. Prior experience with the game resulted in less effort and movements that differ from real swimming. Participants with real swimming experience tend to keep their game play close to real swimming, but when they realized the game mechanics, they also changed their movement patterns. Similar behavior was observed between male and female players.

Performance

There was a difference in the total number of cycles between bad and good performers, as the former (69% real swimmers) were trying to apply the same real-swimming patterns during their game play while the latter movements were sufficiently enough to win the race. In many cases, bad performers had to repeat the movements while good performers could simply rotate their upper limbs and proceed within the game. During the fast swimming phase, good performers maintained a constant rhythm to complete the event, reserved more energy (by following constant speed), and did not have to exert as much as bad performers. Bad performers had to compensate by swinging their upper limbs faster resulting in increased time of play and increased numbers of cycles. As mentioned before, exergames could benefit skill development, if players with movements similar to the real sport are rewarded with higher scores (Papastergiou, 2009). Contrary to Reynolds et al. (2014), in our study the sensor failed to detect precise movements of swimming (Galna et al., 2014), seeming that simple pattern recognition and timings are more crucial than the accuracy of movements based on the real swimming techniques. The simplistic graphics (i.e. the feedback bar) may have encouraged players to focus on core elements of game play and not on their movements (Gerling et al., 2011). Therefore, this exergame might not be applicable in teaching and practicing swimming outside the swimming pool.

Swimming Experience

There were no differences in biomechanical parameters between swimmers and non-swimmers. Players with real-swimming experience had the intention to swim correctly and had to adapt their movements with the visual feedback bar, probably due to the delays in providing sensory feedbacks. As they also lost many points (energy reserves) during their adaptations, they had to compensate in the fast swimming phase by swinging their arms faster. Stroke rate, fatigue, and higher velocity decrease propelling efficiency (e_p) or the ratio of useful to the total amount of work in real swimming (Toussaint et al., 2006). Real swimmers were considering this parameter during their game play, trying to swim properly to maximize their performance. That is why real swimmers had greater hand path distance (similar to stroke length). Since the sensor failed to detect their correct swimming movements and as they figured out the mechanisms of the game play, they changed their technique after some time. This is another reason to doubt the usefulness of the game to help real swimming performance skill development. Lack of differences might be due to applying different strategies to different players and effects of learning, which led the players to switch from swimming technically (correctly) to pragmatically (winning the game).

Exergame Experience

Prior exergame experience did not influence most of the kinematic parameters except the start velocity which is contrary to previous research indicating that exergame experience causes greater movement quantity (Levac et al., 2010). Participants without prior experience were flexing their body more (Figure 3.1 A), and were lifting more body weight returning to the dive in position (Figure 3.1 B), resulting in lower start velocity. Lack of differences in other variables (e.g. hand path distance) might be due to learning different strategies even after a short exposure to the exergame. These results are opposite to previous findings showing that prior experience with exergames provides greater quantity and quality of movements (Levac et al., 2010).

Gender

According to hand path distance, participants played the game with the same intensity, which is contrary to the reports that male subjects play exergames more actively (Lam, Sit, and McManus (2011) and that boys play video games for longer periods than girls (Graves et al., 2008). The weight of the upper limbs might be one of the reasons why females were more active and having greater hand path distance covered during playing. On the other hand, male players played the game faster (based on maximum velocity), in accordance with the literature (Sharp et al., 1982). Moreover, contrary to real swimming (Seifert et al., 2007), our males and females were not different in both start and average velocities and hand path distance, which was expected due to different swimming conditions and applied forces on the body.

Swimming Exergame Experience

Previous swimming exergame resulted in the lower time of swimming, which might be justified by the fact that although players played different techniques, requiring different movement patterns, they learned the mechanisms underlying the game. Players who had their first exposure to the game during front crawl did not explore obvious differences in task restrictions between exergame and real swimming (Davids, Button, & Bennett, 2008). That is why they used fewer arms cycles and were trying to adapt their movements with the feedback bar, resulting in decreased arms' swings. While there are several ways to show game play mechanics (e.g. trial-and-error, instruction manuals, or verbal instructions), they might add extra time to the first gaming session, having a nontrivial effect on overall game experience (Tobin & Grondin, 2009). While previous research showed that a pregame tutorial training does not affect pose accuracy as means of game performance (Whittinghill et al., 2014), our results show that those who played this game before (which also included a pregame tutorial) completed the game in a shorter time.

Comparison to Real Swimming

Because of different body positions and lack of forces applied to the body (swimming in the air which is 800 times lower than water in density), differences in kinematics between the virtual game and real activity were not surprising. While we observed higher values of swimming segment velocity (normal phase: 3±1 $m.s^{-1}$ and fast phase: 4±1 $m.s^{-1}$), previous research reported average velocity in a group of sprinters to be 1.81±0.1 $m.s^{-1}$, and for the distance swimmers 1.80±0.1

m.s^{-1} (McCabe et al., 2011). De Jesus et al. (2012) also reported the velocity in a group of water polo players to be 1.50±0.1 m.s^{-1}. However, it should be noted that duration and difference of these investigations were different compared to our study. During different phases of the game, we observed elbow flexion values ranging from 109±16 to 113±16 degrees and trunk rotation ranging from 34±17 to 40±16 degrees, while elbow flexion of 156±15 degrees and trunk rotation of 62±4 degrees, were previously reported for front crawl (Payton, Bartlett, Baltzopoulos, and Coombs (1999). During 200 m front crawl at race pace, elbow flexion ranged from 40±12 to 152±6 degrees (Figueiredo et al., 2013). Such differences might have happened as players were constantly looking at the screen to receive feedback and therefore, avoided rotating their trunk. It was also stated before that skilled swimmers maintained a more constant stroke length than less skilled (Chollet et al., 1997) and therefore, based on our findings, we can understand that in this exergame, good performance does not necessarily mean following correct real movements (Figure 3.3).

The optimal goal of sport exergames is to mimic the real sport movements, but due to passive-playing nature of the games, players often follow different ways to exert (e.g. head movements increase virtually induced illusory self-motion or Vection resulting to exerting more; Ash et al., 2011). In our study, participants frequently reported that their real movements of swimming were not completely applied in the game, which encouraged them to do simple movements just to win the game. Such comparisons might reveal differences in anticipatory performance in which skilled players are more attentive to the mechanics of the game and such information could be interpreted as learning or adaptation to the movements. Another explanation might be the feedback given to the player during exergaming which is dynamically linked to user input and as players change their game play, the feedback remains unchanged. This might encourage players to maintain their newly adopted game play and exert less.

Movement patterns during exergame play are highly varied and gaming platforms might impose some of these limitations on the players (Pasch et al., 2009). Sport exergame designers could use the biomechanical characterization data during their game development to provide a more meaningful experience, especially if participation in real sport happens before exergame playing (Mueller et al., 2009). There are a number of modifiable and non-modifiable parameters associated with sports exergames. Non-modifiable constraints (lack of actual forces from water or holding a physical racket in hand or positioning) may result in considerable differences in movement patterns. Modifiable considerations, such as input control device and audiovisual feedbacks, currently differ between different consoles and might allow cheating during game play and affect posture and muscle loading (Lui, Szeto, & Jones, 2011). For example, using Nintendo Wii, players can simply move their wrist instead of complete movement in tennis exergame. Proper design is particularly important as many games consist of repetitive movements and, based on the game conditions (e.g. playing against an opponent), movements could be more intense. As enjoyment and other factors may contribute to high exposure to these games, our results could help game designers to prevent musculoskeletal symptoms and could be helpful in designing harder game levels.

The strengths of the current study include using accurate 3D motion capture system and analyzing software, comparing several kinematic variables in the variety of performing groups, and addressing limitations of previous studies. A limitation of the study was that most of our volunteers had sport science background and were physically active. Although we did not explain the mechanisms underlying the game, participants' behaviors might have been influenced by the novelty of the game, meaning that some players might have continued swimming correctly even when they found out that their movements were not translated into the game. While we calculated our sample size based on exergame performance, power in other performing groups might have been compromised and, therefore, considering more subjects to increase the power in different performing groups is advisable.

Conclusion

In this study, we provided the kinematic characterization of swimming exergame and compared the parameters in different performing groups. Although most of the variables were not different among performing groups, different subjects had different game play strategies. As there are differences in upper limb kinematics between those succeeding in the game and those who are proficient in real swimming, our data suggests that better game performers may not necessarily perform better in real swimming and better real swimming performance does not automatically translate into better game performance. Moreover, the motion capture sensor does not detect the correct movements of real swimming and it does not encourage players to swim properly. Therefore, it is most likely not a proper tool for practicing and improving real swimming. In our opinion, the most useful function of the game would be first to have fun and to empower physical exercise induced by game play. Furthermore, it might have the potential for being used in developing basic movements of real swimming (e.g. coordination of the upper limbs) if those correct movements were valorized by the game to distinguish between winners and losers. A detailed biomechanical characterization of exergames during the design phase might help in providing a safer and more meaningful game play, especially when the games are considered for more serious purposes (e.g. education and rehabilitation). A future follow-up evaluation is also necessary to identify potential movement changes in subjects' behaviors throughout the game.

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Chapter 4

Muscle activation during exergame playing.

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Handbook of Research on Holistic Perspectives in Gamification for Clinical Practice

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Abstract

Exergames may provide low-cost solutions for playing, training, and rehabilitation. Exergame user research, studies the interaction between an exergame and users, in order to provide feedback for game developers and safe and meaningful game play. Detailed evaluations and a coding system based on muscle activation levels are necessary to characterize. This is important when it comes to using exergames for purposes other than fun. The purpose of this chapter was to characterize the muscle activation during a swimming exergame and to compare the level of activation during different conditions. Healthy subjects played bouts of exergame using Xbox360 and Kinect. Muscle activation was monitored for desired muscles on the dominant upper limb using wireless EMG system. An investigation of muscular coordination was also conducted to provide activation sequences of studied muscles. Preliminary results showed that UT was the most active muscle in all techniques. Results can provide insights for practitioners to have a baseline on the application of exergames in their routines.
Keywords: EMG, Swimming, Virtual sport, Kinematics, Porto Biomechanics Laboratory, XBOX, Performance analysis, Warm-up, Rehabilitation, Sample size, Profiling, Injury.

Introduction

Since the beginning of the 21st century, videogames have become one of the main sources of entertainment for a wide range of individuals. Statistics show that fifty-nine percent of Americans were playing video games in 2014 (Entertainment Software Association – ESA, 2014). By that time, fifty-one percent of American households were playing computer or video games on different platforms such as computers, videogame consoles (Microsoft Xbox 360, Sony PlayStation, and Nintendo), handheld consoles (Sony PSP, Nintendo DS), iPods, and mobile telephones. On the other hand, a growing body of research has shown negative effects associated with playing video games (Ferguson, 2007; Gentile, Lynch, Linder, & Walsh 2004). Indeed, in the recent years, research has linked excessive screen time to a variety of health and social problems (Brown & Witherspoon, 2002). According to Martínez-González, Martínez, Hu, Gibney, & Kearny (1999), there are inverse associations between leisure-time PA and body mass index (BMI) which works independently from the amount of time spent sitting down affecting BMI directly.

Other authors associated the time children spend watching television, playing electronic games, and using computers, with an increased risk of obesity (Janz et al., 2002; Puska, 2009; Salmon, Campbell, & Crawford, 2006). However, new studies are showing that screen time is not the only factor responsible for obesity (Jackson, von Eye, Fitzgerald, Witt, & Zhao, 2011). Over the past decade, the gaming market has been facing rapid changes, and video games have attracted new audiences, such as women and the elderly. A recent development in video game industry has led to design interactive video games, often tagged as exergames. These games incorporate some degrees of PA during the game play, and players have to use body movements to progress in the games (Peng, Lin, & Crouse, 2011). Such platforms offer motion-sensitive controllers (accelerometers, gyroscopes, cameras, exercise equipment, pads and mats, and pressure sensors) taking the human-computer interaction to another level. These games are usually controlled using large body movements alleged to make the player exert or develop motor abilities during game play. Popular exergame platforms include Microsoft Xbox 360 and Kinect, Nintendo Wii, Sony Playstation

Move, Cateye Fitness, and Xavix. These platforms use gaming technology and mechanics to support various forms of PA.

Previous instruments to measure the impact of video games were questionnaires, observations, and video analysis while newer methods of performance analysis may use log files and biophysical tools. The main differences of methods lie in subjective versus technology-driven aspects of evaluation (Mishler, Lo Bue-Estes, Patrick, & Tobin, 2014). Some methods might be very objective when it comes to applying them in other contexts (e.g. using log files in an exergame designed for healthy people while it is going to be used for stroke patients). To adapt traditional evaluation to exergames, technology-driven methods are required. Today, measuring emotional levels of players is done using different methods. Many tools and methodologies have been proposed to understand user experience playing digital games (Chanel, Kivikangas, & Ravaja, 2012). Psychophysiological responses (e.g. electrocardiography (ECG), electrodermal activity (EDA), and EMG along with psychological questionnaires) are used more and more to measure user experience. By using psychophysiological analysis, researchers can analyze the game experience with greater detail (Nacke, Lindley, & Stellmach, 2008).

EMG measures the electrical signal associated with the neural activation of the muscle; it is an experimental technique which provides information in real time about what is physiologically occurring with respect to nerves and muscles. It offers an objective assessment of when a muscle is active or not and reflects the electrical activity in the muscle fibers of activated motor units (MU). EMG also provides information on the sequencing, or timing, of the activity of several muscles which enables the researcher to focus on skill-related parameters. It also allows studying the changes in muscular activity during training and learning processes. However, we should keep in mind that EMG can not totally reveal what a muscle is doing, particularly in multi-segment movements. EMG measurements have not been widely explored to provide constructive feedback during developing an exergame. The main concern is how these games should be designed to be entertaining and physically suitable and safe for players. Due to the novelty of the field, different playing population, and lack of research in this field, such methods should be employed as part of the design process. Looking at a great number of applications of surface EMG in video games, this chapter intends to provide a basic description and some applications of EMG in exergame research. It also includes the description of the equipment and methods used and the processing of EMG data.

Background

Physiological Aspect of Contraction

The human motor system is responsible for the variety of tasks. Contraction of muscle fibers starts with a neuromuscular synaptic transmission. The central nervous system (CNS) controls the muscle activation by sending/receiving signals called action potentials while causes calcium to enter muscle fibers. This electrical signal is usually proportional to the degree of muscle activation (Hunter, Ryan, Ortega, & Enoka, 2002). It spreads over the surface of muscle fiber and causes series of steps to occur including:

1- A chemical is released from the end of nerve fiber causing a fast change in the voltage of muscle.

2- The electrical signal travels on the surface and along the muscle fibers.

3- Calcium ions are released into the intracellular fluid of muscle fiber following the
stimulation of electrical signals.

4- The calcium ions expose active sites of actin myofilaments to myosin filaments and cause them to attach.

5- Following these attachments, myosin filaments pull the actin which is a response to the electrical signal. This means that the muscle is contracting.

Each muscle has several motor units with several fibers, and each fiber has different action potential (caused by several factors including the deepness of fibers, blood flow, and body fat). There are three types of motor units based on physiological properties: (1) fast-twitch (fatigable); (2) fast-twitch (fatigue-resistant); and (3) slow-twitch. Recording and quantifying these action potentials that activate a muscle is done using EMG study. The surface EMG sensors collect the sum of multiple action potentials. A combination of motor unit recruitment and firing rate are key factors for having greater force. During EMG, a motor unit action potential (MUAP) is recorded in the contracting muscle. Depending on the type of electrode, the captured MUAP derives from small to great numbers of muscle fibers. By using needle electrodes, physiology and pathology of the MU could be studied, and by using modern surface EMG systems, other aspects related to behavior, temporal patterns, or fatigue of the muscle could be explored. They have important implications for sport and rehabilitation where using the needle is not possible or when the assessments have to be repeated several times.

Neurophysiological Control of Movement

Movement process is expressed as an idea, plan, select, and move. The idea defines a goal to be reached which is then converted into a plan telling the best way to achieve it. Muscles are later selected to do the movement. Analyzing movements and muscle activation are ways of trying to understand how brain works which will lead to knowing the processes and decision making. When the brain changes the signals (behavior) based on the outcome, this control of movement is called feedback. An important part of feedback is comparator in which we compare our current output with the desired output. For example, when we play exergames, we constantly use visual information within the game to progress. In the case of sport exergames, a negative feedback leads to change movement from original (or real sport movement) to certain degrees which are enough to proceed in the game (Soltani & Vilas-Boas, 2013).

Learning is the ability to change the behavior with experience and might happen at the early stages of trying a new game. Memory, on the other hand, is the ability to maintain this change over time. In exergames, this might not involve doing the same movements but learning the mechanics underlying the games. Another issue to consider is fatigue which happens as the result of a drop in performance. Fatigue is a complex phenomenon and depends on several factors. Among apparent causes is the shortage of fuel and inability to remove the products of muscle metabolism. There are also several muscular mechanisms of fatigue; namely slower conduction velocity (which is characterized by smaller muscle activation amplitude and longer duration when recorded by surface EMG) and slower relaxation phase.

In most motor experiments of sport games, there might be a difference between task (to do the movements according to the real sport) and performance (what player is doing). Task parameters may include EMG amplitude, timing, load, and accuracy requirement. Performance parameters include kinematic variables (joint position, speed, and acceleration), EMG, and variability from the real expected movements (accuracy). Before conducting such studies, there are always predictions about the relations between task and performance. Such predictions are comparable with postdiction or the relationship between task and performance. Recording EMG during exergame play can provide information regarding agonist and antagonist muscles. Activation of agonist muscle accelerates the limb, and if the muscle activation opposes to the acceleration, the muscle is considered as the antagonist. EMG recording can reveal the patterns of activation (e.g. triphasic pattern) which become eminent when changing the task parameters can cause alterations in these patterns. This leads to a hypothesis called dual-strategy which classifies all the movements into two groups, with or without clear or hidden control over movement time (Latash, 2008).

Why Focus on Exergame?

The main purpose of designing a game is to be enjoyable as well as being profitable for game developers; that is why proper design leads to safe playing and greater game review scores and sales (Fullerton, Swain, & Hoffman, 2004). In the following paragraphs, we will address some of the other concerns with exergames.

Exergame Design

As mentioned in the circumplex model of affect, all feeling conditions come from two neurophysiological systems, one related to valence (pleasure-misery continuous sequence) and the other is related to alertness (Russel, 1980). Facial EMG is generally applied in human-computer interaction (Hazlett, 2006) and video games. With the occurrence of positive or negative emotions, EMG activity of facial muscles increases. For example, increased activity of zygomaticus major (cheek) is related to positive, and corrugator supercilii (brow) muscle regions are related to negative emotions (Witvliet & Vrana, 1995). Based on this, Ravajaet, Saari, Salminen, Laarni, & Kallinen (2006), found their game positive and rewarding but also concluded that using EMG for measuring emotional valence might be misleading.

Exergame and Rehabilitation

The motor function can be improved with therapy and repetitive practice of specific tasks. As rehabilitation is usually a long process which involves repetitive tasks, clinicians are looking for motivating tasks to make the process more meaningful (Weiss, Rand, Katz, & Kizony, 2004). Therapeutic exergaming includes functional and engaging exercises that, through improving motivation, could encourage patients to perform high volumes of practice (Sveistrup et al., 2003). By consequent improvements in adherence levels (Heuser et al., 2007), some studies have also reported increased exertion during training (O'Connor, Fitzgerald, Cooper, Thorman, & Boninger, 2001); that is why they have been described as innovative and promising in rehabilitation technology. Yohannan et al. (2012) measured outcomes of several parameters including active range of motion (AROM) while using Nintendo Wii during rehabilitation of patients. They demonstrated that patients who used exergames in their rehabilitation process improved their AROM with less pain compared to the control group. Brown, Sugarman, & Burstin (2009) developed an EMG-controlled video game to improve motor control of wrist muscles in patients who survived a chronic stroke. In their pilot study, most of the participants improved maximal activation during game therapy sessions.

Howcroft et al. (2012) used different exergames on a group of children with cerebral palsy (CP) and showed that muscle activations did not exceed the maximum voluntary contraction (MVC). They also showed that whenever participants were using realistic movements (that could be successful in the real-world version of the game), muscle activation was even higher. Van Wijck et al. (2012) used the repetitive task training and feedback offered in their music-making exergame on stroke survivors to enhance functional recovery of their affected upper limb. As most of the exergames are designed for healthy players, to use exergames in rehabilitation, the task should be tailored to the target audience and their needs.

For example, Hsu et al. (2011) considered using a bowling game in patients with upper extremity problems. They only found a significant increase in enjoyment (compared to standard exercise group). This proves the necessity of designing the specific game for the purpose of rehabilitation. The task should be continued until the patients are fatigued (Matsuguma, Hattori, & Kajiwara, 2014). Furthermore, it should ensure that the patients are performing the correct movements (Alankus, Lazar, May, & Kelleher, 2010) and the therapist should also be able to monitor their performance. Based on suggestions of Doyle, Kelly, Patterson, & Caulfield (2011), initial requirements for a therapeutic exergame should be (1) generality, covering a variety of upper- and lower-limb exercises; (2) hands-free interaction, so that subjects focus on the movements; (3) easy setup, to reduce complexity and maintain adherence; and (4) real-time feedback, allowing patients to correct their movements. Some other examples of exergames in rehabilitation are: Brain function rehab (Loureiro, Valentine, Lamperd, Collin, & Harwin, 2010; Saposnik et al., 2010), balance training (Brown et al., 2009; Kliem & Wiemeyer, 2010), and EE (Hurkmans, van den Berg-Emons, & Stam, 2010).

Exergame and Injuries

Many injuries come from overtraining and overuse (Marx, Sperling, & Cordasco, 2001) and low levels of muscle strength and endurance are considered as factors in the development of injuries. Observations of Wilson and Brooks (2013) are suggesting that exergames (they evaluated) had at least one exercise considered unsafe by American College of Sports Medicine (2013), showing that users might be prone to injury. Therefore, developing games using musculoskeletal criteria may lead to more effective games and safer game play. Weisman (1983) reported that 20% of elderly refused to play computer games because they were afraid of exposing their deficits. Shubert (2010) showed that most of the commercially available games are not suited for other populations, and game developers should be attentive when designing games for different groups considering their needs and requirements (de Schutter & Vanden Abeele, 2008). Therefore, understanding physical condition (which for example, changes due to age) of players is an important factor when designing games, particularly for the elderly (Gerling, Livingston, Nacke, & Mandryk, 2012).

As shown by Wollersheim et al. (2010), exergames do not increase PA significantly; possible explanations would be due to the gaming platform (e.g. Nintendo Wii only detects hand movements and not the whole body). Another possible explanation would be that as the games involve lots of repetitive movements or the movements are tiring, players are looking for strategies to exert less. This is happening as they switch from emotional playing to technical playing (Soltani & Vilas-Boas, 2013). In exergames, fatigue is unavoidable, but if it compromises performance, the experience of player will be affected (Bachynskyi, Oulasvirta, Palmas, & Weinkauf, 2013). Players should be challenged in a way so they don't lose their interest in playing games (Navarro, 2011). To keep the motivation and continuation of playing, unnecessary complex movements should be avoided. Monitoring muscle activation might adapt the challenges dynamically, which might help players to reach a good balance between challenge and skill levels (Borghese, Pirovano, Mainetti, & Lanzi, 2012).

Warm-Up

The warm-up aims to elevate the core body temperature and stretching is designed to increase the range of motion (ROM) at a joint or group of joints. General warm-up movement is important in performance and to reduce the risk of injury in PA. Both active (low-intensity movements to increase body temperature; Franks, 1983) and passive (using heating pads or ultrasound) warm-ups might be helpful prior to exergame playing. In addition, the movement should imitate the actual movements of the activity (specific warm-up). Warm-up before exergame play might prepare the tissues for greater stresses during the game play and may lower the risk of muscle tendon injury. Recommendation for effective warm-up routines varies depending on the nature and duration of the activity (Bishop, 2003).

Main focus of the chapter

Issues, Controversies, Problems

There are two pathways of EMG: (i) Clinical, which is a diagnostic tool in neuromuscular problems and (ii) Biomechanical, which explores the muscle function and coordination during movements (Clarys, 2000). Most of the studies conducted using EMG, analyzed if muscles are active or not and considered their role in complex sports, exercises, and rehabilitation, as well as quantifying muscular fatigue (de Luca, 1997). EMG has great time resolution, provides quantitative data, requires small system setups, and once signals are recorded, different analyses are possible with the same data set. On the other hand, there is always a chance of movement artifacts which does not allow proper interpretation of the recorded signal. Moreover, EMG recording is generally an expensive and hard to interpret method.

The most common use of EMG in video game analysis is related to measuring facial muscle activities in which reactions and emotional moments inside a video game are recorded (Hazlett, 2006). As mentioned by Nacke, Drachen, & Göbel (2010), EMG of facial muscles allows mapping emotions in the valence part of the circumplex model of affect. Chanel, Rebetez, Bétrancourt, & Pun (2008) also used EMG and self-report analysis to measure emotional states. Muscular activity and physiological patterns were higher when playing in a conflicting situation rather than cooperative which leads to a richer interaction with the game. Ibarra Zannatha et al. (2013) used EMG in their virtual game to determine muscle strength and fatigue effect in stroke rehabilitation. By using biopotential of carpis radialis and BB muscles, they were able to determine fatigue to modify their training program. Park, Lee, & Lee (2014) examined the effects of virtual exercises on muscle activation of the trunk and lower extremities. Their results showed that virtual training causes a significant increase in the activation of tibialis anterior and medial gastrocnemius and, therefore, it could be used in joint stability.

There are two main types of EMG electrodes; invasive and surface electrodes. Invasive electrodes (fine wire and needles) require a needle to be percutaneously inserted into the muscle. The advantages are: (1) an increased bandwidth, (2) analysis of deeper muscles, (3) a more specific pickup area, and (4) the ability to test smaller muscles that are impossible to monitor with surface EMG due to the chance of receiving signals even from distant muscles (de Luca & Merletti, 1988). This phenomenon is called cross talk and there are several technical and statistical approaches available to reduce cross talk (de Luca, 1997; Koh & Grabiner, 1993); such as using spatial filters (van Vugt & van Dijk, 2001). The disadvantages are: (1) discomfort due to needle insertion, (2) tightness or spasticity due to pain, and (3) less repeatable testing situations, as it is hard to insert the needle in the same area of muscle each time.

Surface EMG, on the other hand, provides a safe, easy, and noninvasive way of measuring the energy of the muscle activity. It provides valuable information regarding the activation of a particular muscle group and can allow researchers and designers to implement this information accordingly in their practice and design. The advantages are that: (1) sensors cause no pain, (2) they are mostly more reproducible than wire or needle EMG, and (3) they are very good for movement applications (Figure 4.1). The disadvantages are that: (1) they have large pick-areas which make them prone to cross-talk from other muscles and (2) electrodes can only be used for surface muscles. Due to ease of use with a large number of participants and applicability to be used with children and older adults, we decided to use surface electrodes in our study. From now on, wherever we mention EMG, we mean surface EMG or sEMG.

Figure 4.1. Delsys Trigno wireless EMG system.

Recording EMG Signal

A full understanding of EMG and its application in exergame research requires knowledge of anatomy as well as consideration of signal processing and recording. The general requirement is to detect the signal using electrodes, being able to modify the signal with amplifiers and store the signal with a recorder. The selection and placement of electrodes are important, and it could be acquired either with monopolar, or bipolar or multi-polar arrangement. The monopolar recording is mostly used in static situations (Ohashi, 1997) and situations involving needle electrodes; while bipolar or multi-polar are more common and records the electrical differences between the two or more recording electrodes over the muscle, reducing noise effects.

Muscle Selection

Once researchers considered which muscles might be associated with playing activity, they can place electrodes on those muscles to test their assumptions. This model encourages researchers to understand muscle synergy patterns too. Another strategy is based on clinical reasoning, in which researchers will consider additional muscles for a specific phenomenon and may have a strategy to switch from one level of assessment to another until they discover possible contributing factors that are involved in their practice.

Data Acquisition

There are different models of EMG systems available such as hard-wired, wireless or data logger systems; each has their pros and cons. Hard-wired systems are not affected by ambient noise easily, and allow as many channels as possible to be connected to the subject. On the other hand, they might be bulky and cumbersome; moreover using wires might limit the optimal movement during playing. In wireless systems, the researcher has to place small units on desired muscles which do not limit the subject's movements. Choosing EMG sensors depends on the task, research, and specific muscles to be investigated. As surface electrodes are commonly used for clinical applications (Oh, 2003), technical issues regarding placement and skin preparation can improve the quality of recording in this method.

Skin Preparation

Good EMG signal will be obtained if we prepare the placement site properly. Due to ease of use and non-invasive nature, many EMG studies currently use surface electrodes but good surface preparation is still beneficial. As technology advances, the need to reduce the impedance of skin and electrode is decreased. However, some skin preparation is still necessary for better contact of the electrodes with the skin to improve the quality of recorded signal (Hewson et al., 2003). The preparation involves cleaning the skin with soap and water, dry shaving it and rubbing it with an alcohol-soaked pad to reduce the impedance. This simple task can reduce the resistance of the skin by 200% (Rash & Quesada, 2006). Another important consideration is regarding test condition and exercise. If the task involves slow motion changes, a simple alcohol cleaning might be enough, but in more dynamic conditions (e.g. moving limbs), a more careful preparation is advisable.

Electrode Map of Placements

The European recommendations for surface EMG, also called SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles) is attempting to standardize EMG assessment procedures (Hermens et al., 1999). For many clinical applications, the belly of the muscle is chosen for the electrodes to be placed and, to assure repeatability of the exact location of placing electrodes, using bony landmarks as the reference is highly advisable. As the recordings are usually contaminated by crosstalk from other muscles (which can cause misleading the identification of the muscle action), researchers should decide if they want a general or specific recording and place the electrodes according to their purpose. In general placement, the researcher can record from a general region. The specific electrode placement tries to record the muscle activity of certain muscles that are usually close to the surface and relatively easy to isolate. Here, we describe electrode placements for five muscles:

Upper Trapezius

The position of the arms in relationship to the torso may be the major factor influencing the muscle’s activation. The electrodes are placed parallel to the muscle fibers of UT. They are placed in the middle of the spine (C7) and lateral point of the acromion, and approximately 2.5 cm away from the ridge of the shoulders (Figure 4.2). Raising the shoulders, rotating the head, and pulling the shoulder blades together help to identify the position of placement. Artifacts include ECG (which could be eliminated using proper filter range) and breathing.

Figure 4.2. Electrode placement for the UT.

Biceps Brachii

This muscle is responsible for forearm flexion, supination, and shoulder flexion. Placement of electrodes on this muscle which is two-blinded is done by flexing forearm on a supinated position and putting them on a line between the medial aspect of acromion process and the cubit fossa in the direction of muscle fibers (Figure 4.3).

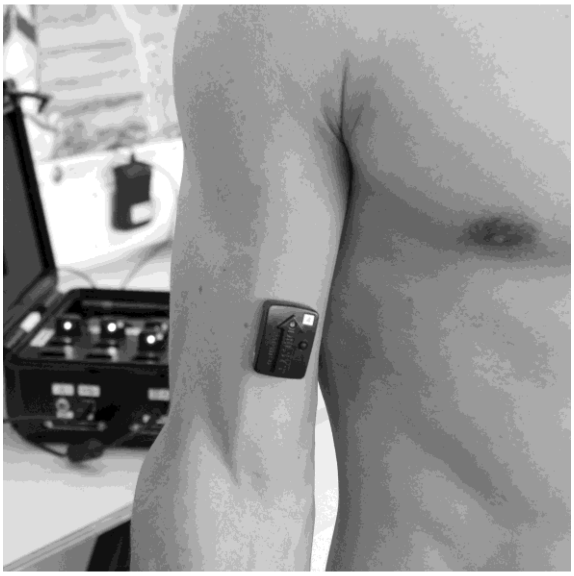


Figure 4.3. Electrode placement for the BB.

Triceps Brachii

Placement of TB which is responsible for elbow extension and adduction and extension of the shoulder is done by monitoring the long head of the muscle; placing the electrodes parallel to the fibers and at the middle of the line between the posterior crest of the acromion process and olecranon (Figure 4.4).

Figure 4.4. Electrode placement for the TB.

Latissimus Dorsi

Placement of electrodes of LD which is responsible for medial rotation, adduction, and extension of shoulder/arm, participation in rotation, lateral bending, and extension of torso is done by palpating the scapula; placing the electrodes approximately 4 cm below the inferior border of scapula, half the distance between the spine and the lateral edge of torso and positioned almost 25 degrees obliquely (Figure 4.5).

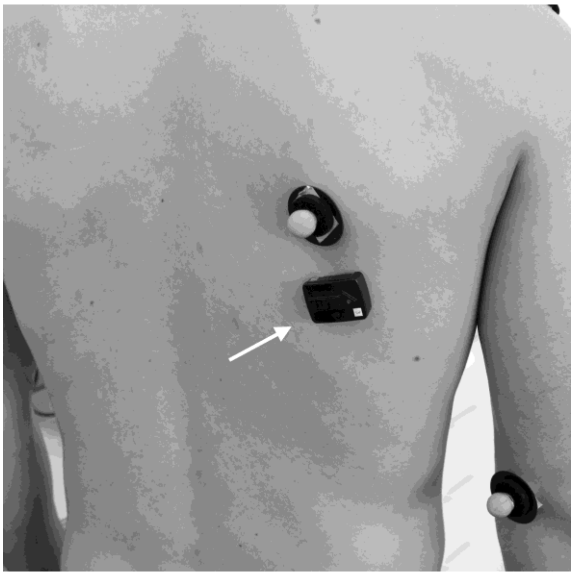


Figure 4.5. Electrode placement for the LD.

Erector Spinae

This muscle is responsible for main trunk moves and monitors stabilizers. The sensor is placed at the L3-4 level; about 4 cm lateral from the midline (Hashemirad, Talebian, Hatef, & Kahlaee, 2009; Figure 4.6).

Figure 4.6. Electrode placement for the ES.

Noise and Artifacts

There are many sources of unwanted signal (noise) collected with the wanted signal. A common source of noise is related to the heart beat, or ECG artifact. This should be specially noted when electrodes need to be placed on the left side of the body and close to the heart which will be shown both in raw and processed EMG signals. Movement artifact is another massive deflection in the EMG potentials of the raw EMG recording and happens because the electrodes move around (relative to the detection site). Improper placement of the sensors may result in movement artifacts. Using better gels, standard adhesive tapes, securing sensors with nets and taping are additional strategies to keep the sensors in place. Another source of noise is from 50/60 Hz energy of electrical cords that affects EMG signals significantly. Assuming a good performance of the amplifier and proper skin preparation, the average baseline noise should not be higher than 3-5 mV. The human body is a good electrical conductor but this conductivity changes with tissue type (e.g. muscle vs. fat mass), thickness, physiological changes, and temperature. These parameters vary from subject to subject and even within subject (if the tests are not done in the same conditions).

Pit Falls

Good history and physical examination are necessary before analyzing EMG. For example, sometimes a neck pain might be associated with paresthesias. However, abnormal results might not always represent pathology but due to an error by the eletromyographer. Temperature is another important factor that could affect amplitude and latency. Usually, a 32 degree Celsius (°C) temperature for upper limb and the lower limb above 30°C is ideal. As mentioned before, adipose tissue assuages the EMG signal, and it is important that the researchers be attentive when selecting the population for the study. Ideally, researchers should measure the thickness of adipose tissue around the placing site, rather than just measuring the overall body fat percentage. Factors such as age, height, and weight can significantly affect EMG recording and they need to be addressed appropriately.

EMG Data Processing

Improvements in both hardware and software (signal processing techniques) have changed processing and analyzing of the data. As raw EMG is low voltage and could be covered by electrical noise, the signal should undergo treating processes to be correctly interpreted.

Filtering EMG Signal

In most of the movement studies, the raw signal is used; however, the main problem associated with raw EMG is the true interpretation of the signal. Researchers developed ways to process the EMG signals and make it easier to understand. Rectification and smoothing out the signal are among normal procedures to obtain interpretable data. Rectification changes the raw EMG signal to a single polarity (usually positive), and eases signal processing (Landa-Jimenez et al., 2014). As comparing the quantified EMG would be affected by adipose tissue, muscle mass/cross-sectional area, age, and sex between the subjects, a technique called normalization is being used to control these variables. Several forms are available for normalization and among all, MVIC is frequently used (Ekstrom, Soderberg, & Donatelli, 2005).

MVIC normalization provides an estimation of relative invested neuromuscular effort during exergame task and shows at what capacity levels the muscles are working. After warming up, which includes stretching and low aerobic exercises lasting 5 to 10 minutes, participants are asked to do three MVICs for the muscle groups of interest. In our study, each MVIC lasts for 10 seconds (first three seconds for preparation and gradual increase in exertion, four seconds for maximal exertion, and the last three second for a gradual decrease and resting) and the middle four-second contraction is considered and then averaged over three trials of the MVIC. All the EMG data points are divided by MVIC value, and it represents a percentage between 0 and 100%. All values are relatively compared to the maximal effort, and therefore comparisons between muscle and different subjects would be possible. Working with the special population (e.g. patients with cerebral palsy or low-back pain), they cannot/shouldn’t perform MVIC, and alternative methods should be considered. A clinical concept called “accepted maximum effort” which is the maximal level of exertion that could be tolerated by a person is advisable and could act as an MVIC replacement (Khalil et al., 1992). Lower cutoff point filters will delete much of the electrical noise, and upper cutoff point deletes tissue noise. This is practical while using different systems with different technologies. Upon amplification and filtration, the signal is ready for visual display and quantitative presentation.

Analyzing and Interpreting EMG

Amplitude (an indicator of the magnitude of muscle activity) and frequency (firing rate ranging between 1 Hz and 500 Hz) are important characteristics of EMG signal. For analyzing amplitude, one might use peak to peak amplitude, average rectified amplitude, root mean square (RMS) amplitude, linear envelope, or integrated EMG. Following amplitude analysis, and to analyze frequency characteristics of the EMG, turning points and zero crossings, or mean and median frequency might be used. Other techniques such as onset-offset analysis (which is important for time analysis), phase-plane (which tries to link the kinematics of the movement with EMG), and polar plots (which describes the spatial distribution of EMG during an activity) diagrams and other analysis techniques might be also used (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2013). The muscle on- and off-timing patterns and relative increase and decrease in muscle activity are the main parameters extracted from the signal. Beside this, researchers might also use EMG as changes in the signal as the muscle fatigue, particularly in the frequency domain.

Documentation

Documentation allows the researchers to know what has been done during the test, allowing them to have a basic understanding of analysis and enables them to share information. It covers four main items: Subjective documentation, Objective documentation, Assessment, and Planning. Subjective documentation involves a self-report of the subject. If the assessment is related to pain, the researcher should ask subjects to rate their pain on a scale of 1 to 10 for each part of the study/visit and should chart the subjects' pain (Borg, 1970). The second part is objective documentation, in which EMG offers useful information to share with others. The next part is the assessment of the information where comments about how to improve the games and what's potentially dangerous (especially by using repetitive movements) are mentioned. The last layer refers to treatment planning, in which the researchers decide about the plan they want to use. For example, if they are using exergames in rehabilitation, the results might help if such games are helpful for patients or not. Comprehensive list of elements to document may include:

1- Target muscles (anatomical markers usage if relevant).

2- Electrode location and electrode locator templates.

3- Electrode type and manufacturer.

4- Inter-electrode distance and orientation to muscle fibers (which should be standard).

5- Ground electrode placement (if relevant).

6- Instrumentation specification: band pass filter range, site of pre-amplification, notch filter, type of signal display (raw versus processed), integration times (time constants), common mode rejection ratio, input impedance, signal-to-noise ratio, time constant, type of signal processing (i.e., RMS), and sampling rate for computerized systems.

7- Informed consent for procedures and objectives of analysis.

8- Positioning and movement of the subject.

9- Work: rest times, the number of repetitions, task duration.

10- Verifying if EMG signals are being received from the muscles.

11- Verifying if the researchers attempted to document/eliminate the cross-talk from other muscles.

12- Normalizing methods (maximum voluntary isometric contraction, submaximal voluntary isometric contraction, EMG defined as a percentage of the peak magnitude recorded during a defined dynamic movement, EMG defined as a percentage of the average magnitude recorded during a defined dynamic movement, EMG values averaged over a defined movement sequence are expressed as a percentage of the average during another reference movement, EMG values from homologous muscles are expressed as a left–right percent difference, frequency spectral analysis).

Assessment Consideration

General reports regarding the findings might include the following:

1- Body posture/position of limbs (Kinematics).

2- Baseline values (resting).

3- Peak amplitude attained during the movement.

4- Recovery from movement (baseline level and rate of recovery).

5- Multi channel comparison of muscles (relative timing recruitment/silence during phases of movement).

6- Interpretation of the findings.

7- Recommendation for further assessment

Sample Size in Exergame Research

One of the main questions in exergame research is ‘How many subjects are needed for the research?’ The answer is important since the amount of collecting data is not always a quick matter. Sample size estimation is an important aspect of exergame experimental design, because without these calculations, the sample size may be too high or too low. If the sample size is too low, the experiment will lack the inferential power to provide reliable answers to the questions under investigation. If the sample size is too large, time and resources will be wasted, often for minimal gain (but always tending to increase inferential power). The main purpose of statistical power analysis is to guide the planning of exergame research. Power analysis is the ability to detect a significant effect (a relationship between the variables), where one exists. When a pilot study is conducted, power analysis can help to make sure that the procedures are working well enough to encourage the researchers to consider a larger scale research. On the other hand, participants might be a minority population (e.g. children with unusual health problems) who in this case, are often hard to study in a large number of participants.

One method for determining sample size is to use sample size calculators that are widely available on the internet. They are often available as free resources. Some of them are provided below:

1- Creative Research Systems – www.surveysystem.com/sscalc.htm.

2- Raosoft – www.raosoft.com/samplesize.html.

3- National Statistics Service (Australia) – www.nss.gov.au/nss/home.NSF
(access via statistical references).

Another program is called G*Power which has been available for several years. It's a tool to calculate power analyses for many statistics tests. It can also calculate effect sizes and display the results graphically (Faul et al., 2007). It is important to consider power, effect size, the number of participants, and type of design/statistics to increase chances of finding an effect.

Pilot study: Muscle activation during swimming exergame

In the following part, we will take a look at an experiment we are conducting and a part of which was published in the XII international symposium on biomechanics and medicine in swimming (Soltani, Figueiredo, Fernandes, Fonseca, & Vilas-Boas, 2014). Our main aim was to provide a muscle activation profile for a swimming exergame and to compare the level of activation in different conditions.

Procedures

10 male subjects (age 24.1±3.3 yr; body mass 71.7±6.1 Kg; height 175.1±7.2 cm) played bouts of swimming exergame. Anthropometric measures were taken, and the participants were familiarized with the equipment and the procedure. Wireless EMG sensors were placed on dominant upper limb/side of players. Five muscles of interest (BB, TB, LD, and UT) for this study were employed. These muscles were frequently used in swimming (McLeod, 2010). We also monitored the activity of ES as it was used in this particular game. Placement of electrodes was according to SENIAM recommendation (Freriks et al. 1999), and EMG was recorded using a Trigno Wireless system (Delsys Inc., USA) at the sampling rate of 2000 Hz. In order to relate EMG and kinematics, spherical reflective markers (size: 20 mm) were placed over the skin on the anatomical landmarks based on a custom links segment model as follows: 7th cervical vertebrae, acromio-clavicular joints, lateral and medial epicondyles approximating elbow joints, wrist bar thumb side and pinkie side (radial styloid and ulnar styloid), dorsum of the hand just below the head of the second and fifth metacarpal, inferior lower border of scapula bones, sacrum, sternum, and mid-superior, anterior superior aspect of iliac crest. The setup was in accordance with the commonly used model (Rab, Petuskey, & Bagley, 2002).

The 3D position of each marker was simultaneously recorded at 200 Hz using a 12-camera opto-electronic motion capture system (Qualisys AB, Gothenburg, Sweden) within acquisition software (Qualisys Track Manager, Qualisys AB, Gothenburg, Sweden). Figure 4.7 shows a subject with the reflective markers and wireless EMG sensors placed on his body. For this study, we considered only the upper limb kinematics. A dynamometer (Biodex 4, Biodex Medical Systems, Shirley, NY) was used to obtain MVIC. Three MVIC attempts were obtained, each lasted 10 s (3 seconds of rest in the beginning, 4 seconds of contraction, and 3 more seconds to reduce gradually) with one minute rest between the attempts. The MVIC values were chosen from the highest value of the three attempts to normalize the trial data. During MVIC, verbal encouragement was provided.

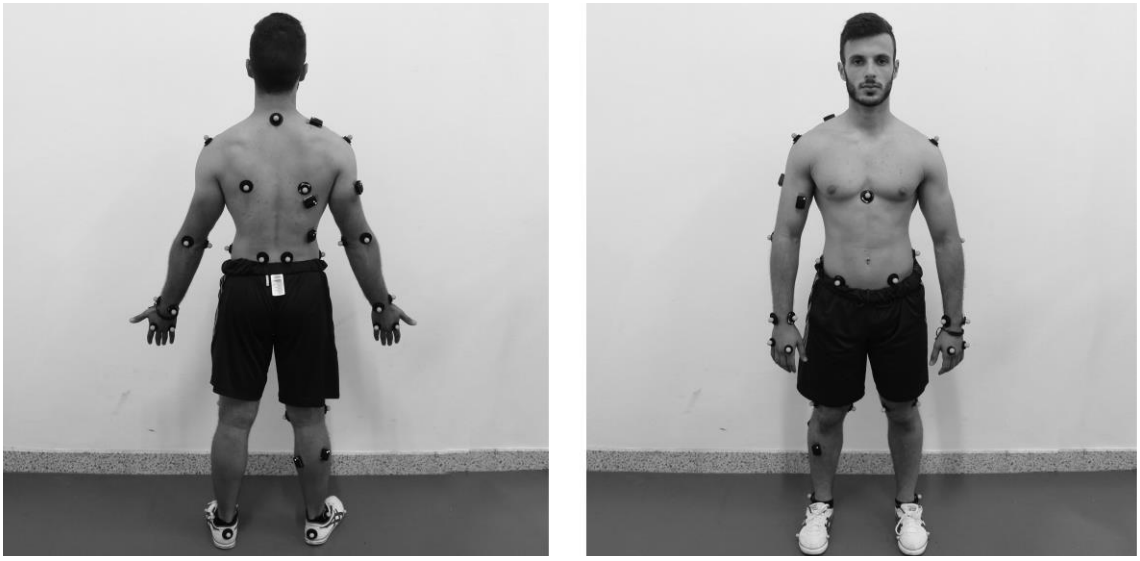


Figure 4.7. A sample map for EMG sensors and reflective markers placements.

The exercise task was a swimming exergame designed for Xbox gaming platform. The software used was Michael Phelps: Push the Limit (505 Games, Milan, Italy), a game that offers different swimming techniques and uses Kinect, which connects to the Xbox via a USB cable allowing users to interact physically with the game. After arriving at the laboratory, participants got familiar with the device through navigating the menus and exploring different options. As part of the game, they watched a brief instructional video from the game in which playing with the game was demonstrated. The game was divided into two phases of normal and fast swimming. Four different swimming techniques were randomly played during this study. Each event consisted of 100-meters of virtual swimming. At the beginning of the game, players can cheer the audience by moving their arms up and down and get extra energy (Figure 4.8 A). Subjects had to stand in front of Kinect and slightly bend forward (Figure 4.8 B) and as soon as they saw “Go!” command, they had to return to normal standing position (Figure 4.8 C). After that, they have to swing their arms according to the technique (no leg movement) to move the avatar in the game (Figure 4.8 D - 4.8 K). When they finished one lap of the pull, they have to push their hand forward to return (Figure 4.8 L). At the end of the event, they had to drop both arms (Figure 4.8 M) and then raise one arm to finish the race (Figure 4.8 N). To prevent players from swimming too fast or too slow, there is a spectrum on the screen which indicated if the cycle frequency is at the moderate level. At the middle of the second lap, there is a possibility to swim as fast as possible called “Push the limit.” If players swim with a constant speed, they can save energy on a so called energy bar and reuse it in the push the limit phase.

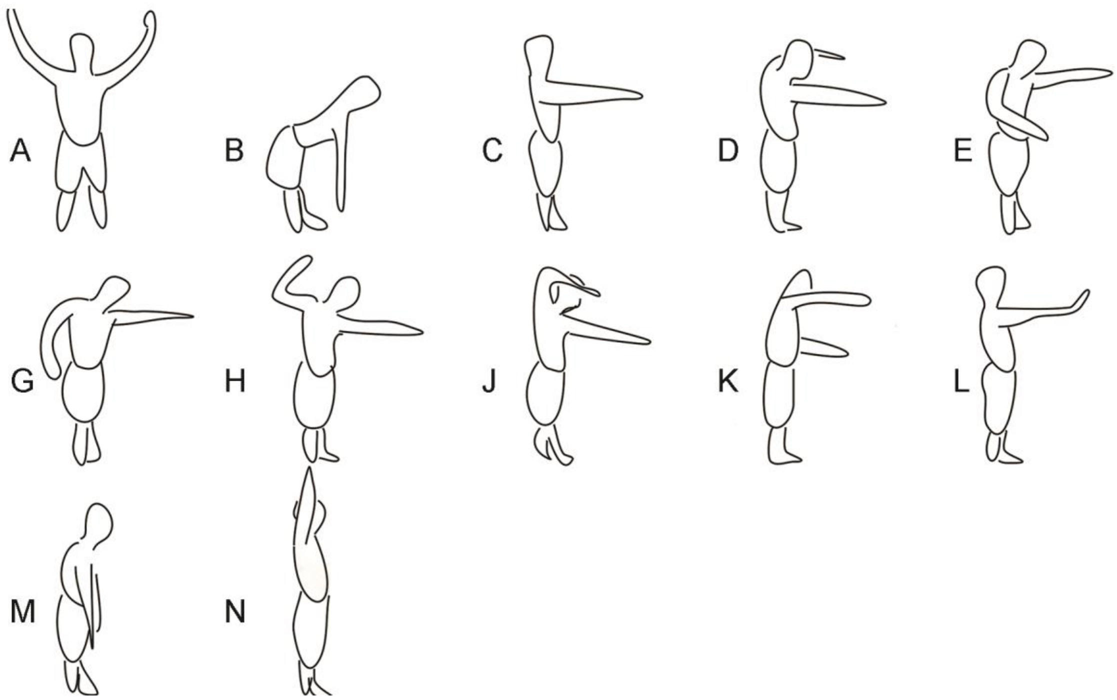


Figure 4.8. The body position during front crawl.

EMG data was processed using EMG Works Analysis 4.0 (Delsys Inc, USA), and it included signal filtering between 20-450 Hz, full-wave rectification and RMS envelope calculation using a 150 ms window. This process was performed for both the MVIC and the trial data. A paired t-test was run on each technique to determine whether there is a statistically significant mean difference between the five muscles in normal and fast mode ($p < 0.05$).

Preliminary Results

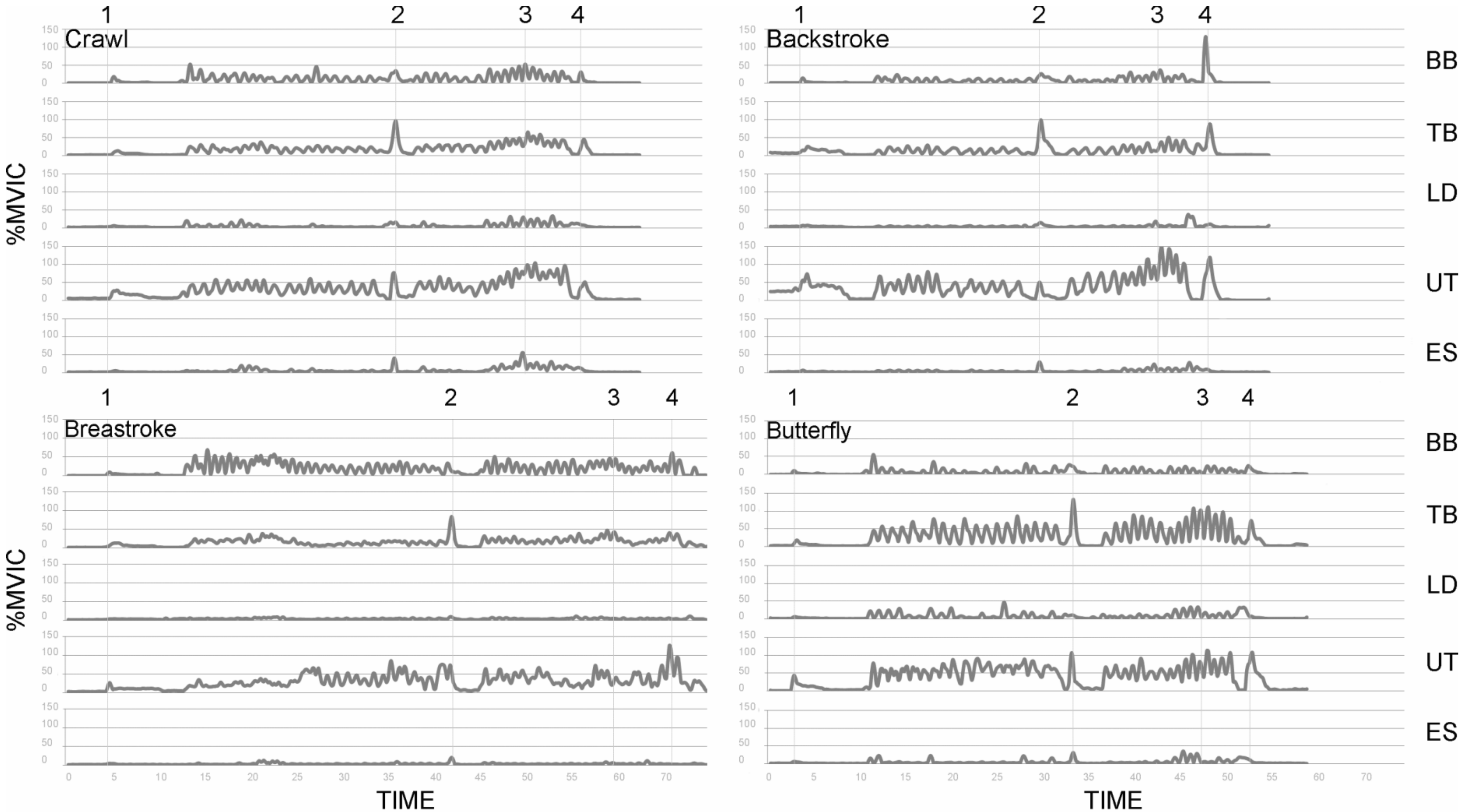
Table 4.1 presents RMS EMG mean±SD data expressed as a percentage of MVIC, recorded during “normal” and ”fast” phases of swimming. The pair t-test showed a significant change between normal and fast swimming in breaststroke ($t(4) = -4.27$, $p = 0.01$), butterfly ($t(4) = -3.49$, $p = 0.02$), and crawl ($t(4) = -3.80$, $p = 0.01$).

Table 4.1. Muscle activation levels (normalized to %MVIC) during swimming exergame with two playing velocities for selected muscles.

		Bi	Tri	LD	UT	ES
Back Crawl	Normal	4.9±2.4	17.0±16.2	15.4±10.4	47.0±15.5	6.8±4.1
	Fast	8.2±5.0	23.7±22.1	21.7±18.1	69.3±18.6	13.4±7.3
Breaststroke*	Normal	10.0±5.5	19.0±18.2	11.1±6.7	29.0±19.3	5.0±2.6
	Fast	18.3±7.2	28.8±31.7	20.6±12.4	46.1±40.8	8.1±4.5
Butterfly*	Normal	5.6±2.0	23.4±21.3	24.4±32.7	43.8±19.0	5.5±2.4
	Fast	9.7±3.9	33.1±26.2	50.8±66.8	65.4±34.4	15.8±10.2
Crawl*	Normal	8.2±3.1	16.2±15.6	11.8±7.6	39.7±22.5	7.1±4.1
	Fast	15.2±4.8	23.0±24.6	22.9±14.9	63.7±31.5	18.1±13.0

*: significant changes were observed between normal and fast swimming in muscle groups

Figure 4.9 presents a visual time sequencing of muscle activation for different techniques. Figure 4.10 shows a sample movement pattern of a player in the front crawl along with the behavior of the signal according to the position of the player.



1: Start; 2: Return phase; 3: Fast swimming phase; 4: Terminating the race; Values of %MVIC ranges from 0 to 150% and each line represents 50% of muscle activation.

Figure 4.9. Time sequencing of muscle activation in different techniques.

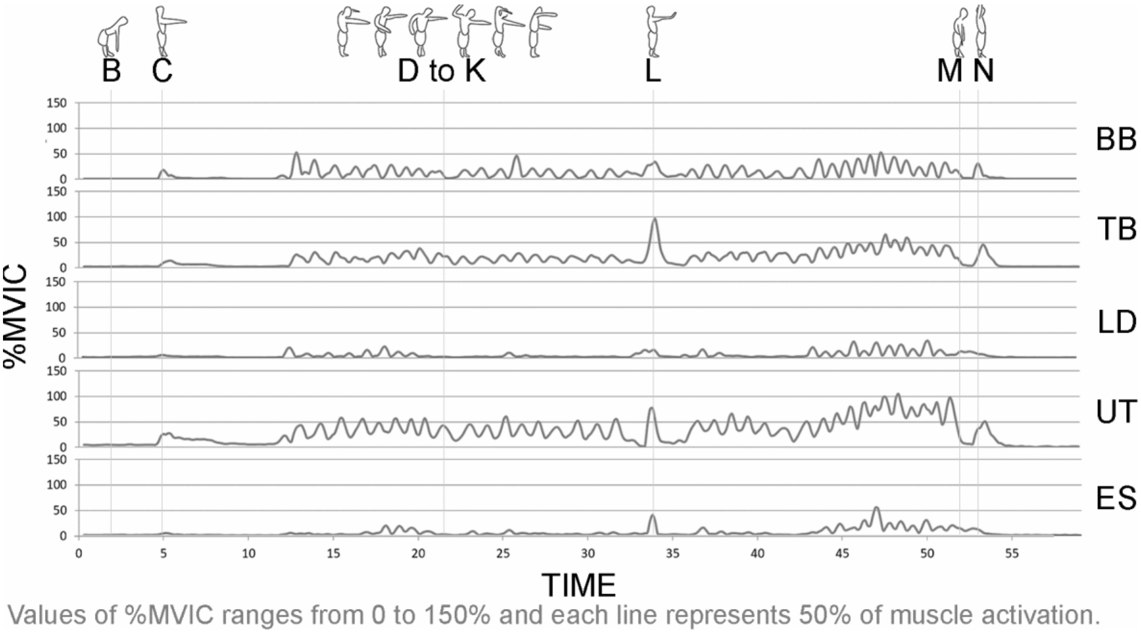


Figure 4.10. The signal behavior according to the position of the body in front crawl.

Discussion

Preliminary results show higher contributions of UT in all techniques. This is probably because players always have to hold their upper limbs up/front (flexed shoulder). Particularly high values were obtained for the back crawl, where expressive shoulder flexion/rotation is required. In addition, as players were focused on the game and television, they avoided rotating their bodies which may justify why there were not any significant changes between normal and fast swimming as players had to exert a lot during both phases. When players perform the movements of swimming out of the water, gravity is the only relevant resistance they confront, and it will affect the movement as the subjects want to lift their upper limb (i.e. in the so called recovery phase and in the last part of pull).

The investigation of muscular coordination can be performed using kinematics while the EMG signals are cut into cycles (Figure 4.11). Typically, most important muscles around a joint or most muscles within a group could be measured. The cycle begins when the dominant hand is completely extended in front (Figure 4.11 C). The level of UT activation is close to the maximum. This is happening due to upward rotation of the shoulders. LD quickly joins other muscles to assist this phase (similar to the first propulsive phase of real swimming). At the elbow and during (Figure 4.11 E), BB (one of the elbow flexors) begins to contract as the player rotates the hand inward and gradually into a flexed position. This happens as ES and LD are helping to rotate the body. Following that, TB activity, which was reduced to the minimum while the hand in the lowest position (Figure 4.11 G), starts to increase again extending the elbow which brings the hand backward and up (Figure 4.11 Q). In the real swimming, this phase is called recovery in which deltoid and rotator cuff are assisting TB in removing the hand from water to start a new phase. As in swimming exergame, players tend not to rotate their trunk due to facing the television, they would compensate by flexing the elbow. That's why there an increase in BB activity from Figure 4.11 E – 4.11 Q.

TB is the main stabilizer muscle as the activity of UT decreases in this phase. When the hand is completely in the back (Figure 4.11 Q), player flexes his arm to return the arm in order to start a new phase. Once again, as the player did not rotate his body completely, during Figure 4.11 H, the hand is not fully extended in the back, causing UT not to be active much, and ES acts as a core stabilizer. From that point, the activity of BB starts to decrease again but TB starts to extend the arm again. When the arm is in the highest position (Figure 4.11 J), the activity of UT is almost maximum as it is stabilizing the arm too. As the arm is extended too, the activity of UT reaches the maximum. From that point, the activity of TB starts to decrease again while LD accompanies the gravity in lowering the arm (Figure 4.11 K).

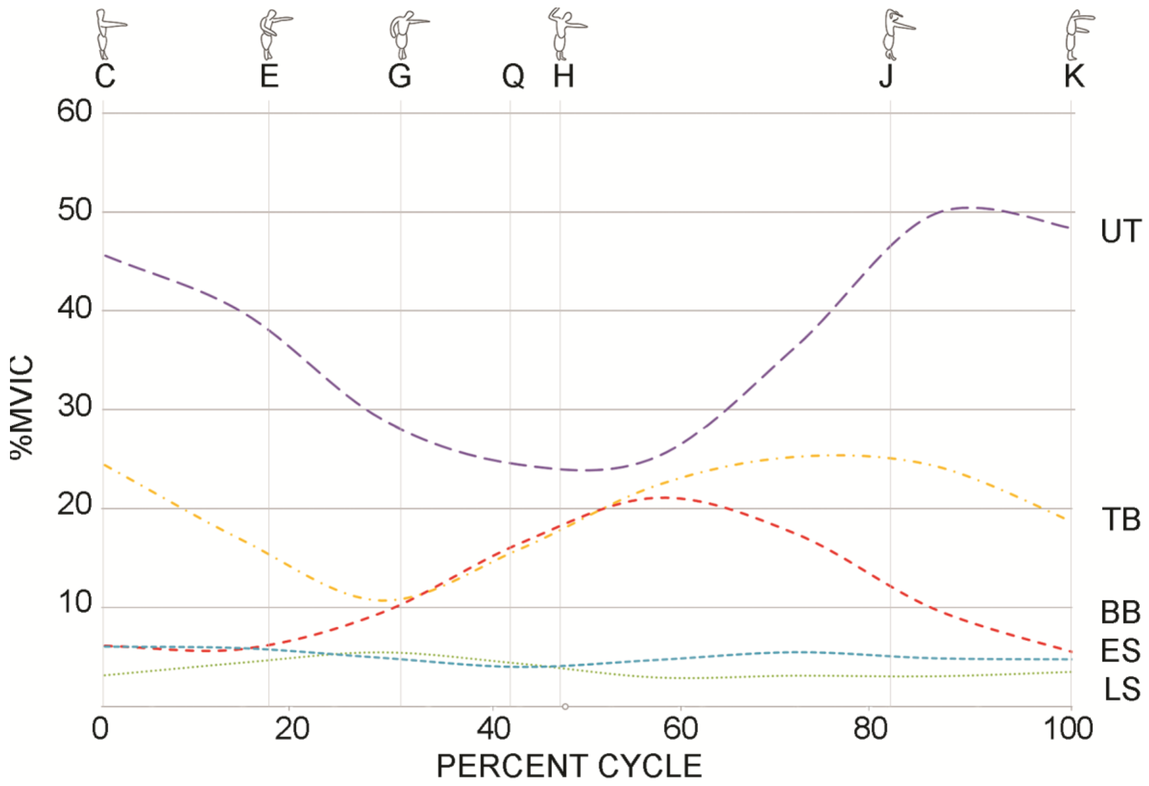


Figure 4.11. Muscle activation patterns in one cycle during front crawl based on the position of the dominant arm.

Solutions and recommendations

Problems

EMG data collection is generally not a fast process. Straker et al. (2009) measured EE and EMG in different exergame platforms but did not normalize their results to reduce the time burden on their participants (children). Although wireless EMG sensors are easy to apply, the subject preparation and MVIC recordings for each muscle are time consuming. Our data collection took approximately one hour per subject (participation in game and recording MVIC for five muscles) which might not be tolerable for children and elderly. In such cases, normalization can also be performed using a standardized reference contraction, and the muscle activation is expressed as a percentage of reference voluntary electrical activity (%RVE). Of course, time issues vary for different groups of participants and different approaches. The limitations on time highlight the importance of planning, scheduling, and piloting the EMG study.

We were using the standard adhesive tapes for our EMG sensors. However, after the MVIC recording and as the subjects start to sweat, there was a chance for the sensors not have proper contact with the body. This is important to keep the recording time as short as possible for having a proper signal. We were using securing nets for UT and ES to make sure that the sensors are not moving during the game play. Because of the rectangular shapes of the sensors and by using nets, we made sure that the sensors are in place especially for rotational movements of the arms. Exergame researchers should know what each sensor type measure. During these kinds of experiments, we should keep in mind that human body might be influenced by other parameters such as room temperature, supervision of investigators, noise, and many more that could affect our interpretation of muscular activity. By controlling unwanted factors, we can improve signal-to-noise ratio while measuring muscle activation.

Application OF EMG

Muscle activation profile may allow adapting the activity according to the needs of participants. Regarding exergame design, profiling makes the game closer to the real activity. In the case of virtual swimming, it might be a method to compare the activation pattern of the muscles with the real swimming. If proved similar, it could be used as an alternative; especially when measuring the real activity is practically hard (Marion, Guillaume, Pascale, Charlie, & Anton, 2010), albeit feasible. During repetitive movements which involve fatigue and changes in temperature, EMG-force relationship could be useful (Dowling, 1997) and a fast Fourier transform (FFT) analysis of the frequency response can be used to identify the occurrence of fatigue. Creating EMG profile in each activity may allow full program/game design guidelines and decisions. It does provide details on how each activity can benefit or harm the subject. If you decide to use exergames in your practice and if you would like to target one specific muscle, EMG profiles can give you useful insights.

However, we should be aware of several considerations while applying exergames. The repetitive nature of most exergames might develop muscle imbalances and fatigue. Some muscles might face overload while others may not even be used. These muscle imbalances may also create secondary postural imbalances. As exergames might be used in other domains such as rehabilitation and in an unsupervised and self-directed setting, such understandings are crucial for prescription and secure training session. The changes that we observed in our study may be appropriate for the healthy population. We should note that training and games should be specific to the population. As mentioned in a systematic review by Barry, Galna, & Lynn Rochester (2014), using exergames in rehabilitation is still very novel. Concerns regarding safety, feasibility, effectiveness should be address before implementing them in clinical practice. Dogan-Aslan, Nakipoglu-Yüzer, Dogan, Karabay, & Özgirgin (2012) also suggested that combinations of EMG and conventional therapies are more successful. Finding the suitable exergame for certain groups is a challenge. The commercial exergame titles and platforms are cheap, and it might provide opportunities to promote PA for elderly and disabled patients (Higgins, Horton, Hodgkinson, & Muggleton, 2010). On the other hand, specific exergames that meet certain needs of the patients might be expensive as they are not mass produced.

Applying EMG in Game Design

Depending on the type of platform and game title, some muscle groups might be more active than others. In some platforms such as Nintendo Wii, players have to hold a sensor while playing which gives extra activation on wrist extensors. All exergame platforms have advantages and disadvantages for clinical research. Inaccurate sensors might cause the players to repeat the movements or might generate frustration which leads to decrease adherence. By using wireless EMG sensors and kinematics, muscle activity signal can be recorded during the gaming session and could be used to modify the games before final release, which seem to be a better approach than subjective methods (i.e. using questionnaires during or after game play) of evaluation.

Sport exergames might be used as a tool for training real sports. Therefore, proper exergame exercises need to be selected carefully. Two concepts of transference and isolation can help in choosing the exercises. Transference is the ability of an exercise in strengthening muscles in a way that helps a skill. Isolation is selecting a specific activity that targets one muscle or muscle group in order to make that muscle stronger. Soltani & Vilas-Boas (2013) considered learning during a sport exergame. They asked real swimmers and expert exergame player to play bouts of swimming exergame. They concluded that real swimmer applied the real swimming mechanics during playing while expert players were swimming technically (not mimicking real swimming or emotionally) to win the game. In their study, the authors used kinematics of movement as a result of learning. Therefore, the swimming exergame may not be used in transference as most of the players tend to use technically rather than emotionally (correctly). However, it might be a good tool in teaching basic concepts of real swimming to children and those who don’t know how to swim at all.

As mentioned by Lui, Szeto, & Jones (2011), one third of players experience degrees of body pain during playing video games. Among reported areas, neck pain is commonly occurring. Our results confirm this as UT was the most active muscle during the game play. This justifies the importance of warm-up routines and adapting the games according to the needs of players. By using small EMG sensors, muscle activation can be recorded without interrupting the game play. This information can be used to modify different events of the game.

Exergame Ergonomics

Repetitive stress injuries are becoming a concern in biomechanics, ergonomics, and rehabilitation. Researchers can use many EMG tools to identify tasks that could potentially be dangerous to the body. In the case of exergames, even low-intensity activities could be fatiguing if conducted for a long time. As many games consist of repetitive tasks, the site of fatigue could be determined using EMG techniques, and EMG analysis could be a useful tool in redesigning and reducing fatigue.

Future research directions

Future research should investigate exergames qualitatively and quantitatively. Future studies could incorporate real world practices (such as warm up, stretching, instructions, and feedback) and analyze their effects on exergame performance. Dividing the movements into different phases using kinematics, and comparing the EMG levels in different phases, could show in what part of the movement the incidence of injury is more probable. As exergames consist of lots of repetitive movement, such approaches could be beneficial in designing games avoiding extreme movements that could potentially harm the body. EMG could be used to compare the game play behavior of different players. After playing for some time, most of the players tend to switch the way they play to spend less energy. EMG and kinematics could be used to identify these points and adapt the game levels for a more meaningful experience. Adding a virtual competitor (computer or another peer) increases the exercise effort among competitive tasks for both normal (Anderson-Hanley, Snyder, Nimon, & Arciero, 2011) and stroke patients (Chuang, Sung, Chang, & Wang, 2006). Future studies should compare muscle activation with the presence of peer pressure.

Conclusion

In this chapter, one possible way to analyze exergames has been outlined. We introduced different challenges using EMG for the game analysis, describing the process from obtaining raw data to an interpretable signal. We covered the sufficient recommendations of SENIAM and the equipment used in recording EMG. EMG profiling could predict user's effort and measure their results. This can affect the development of a game and will allow developers to gather data from real world users to improve the game using an objective process. Evaluating exergames from different aspects proves their applications and their types of measurements and how to measure them are the main areas. Measuring performance is one of the categories of the impact of the exergames and includes the factors in the person's ability to finish a task. Profiling exergames using muscle activation might prolong game play, especially when lots of repetitive movements are involved.

Injury biomechanics research applied to exergames is trying to prevent trauma through game modification. To do so, it is necessary to understand what the mechanisms of injury are and to have an understanding of human tolerance to game impact. EMG research might help in identifying and defining the mechanisms of injury, and it quantifies the responses of human muscles to these mechanisms. The individual's playing experience is important in exergaming as it might be used to foster fitness goal or to be used in other contexts. For a better exergame, the game should have a good user experience (based on the purpose of user evaluation). AVGs are gaining popularity in different populations, and game developers might use emerging technologies to design better games. Game user research and human computer interaction can offer better understating of player's experience with AVGs.

Making the decision to use an AVG in other contexts (such as rehabilitation or teaching) is based on clinical reasoning (Schenkman, Deutsch, & Gill-Body, 2006). Using patient-centered focus and detailed analysis, makes the decision on inclusion of games in practice easier. More research to characterize and showing the efficacy of games will help to incorporate exergames into practice.

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Key terms & definitions

Electromyography: Electromyography is a technique for recording and evaluating the electrical activity produced by skeletal muscles.

Exergame: A portmanteau of “exercise” and “game” is a term used for video games that are also a form of exercise.

Isometric exercise: Muscle action in which tension is developed, but there are not any changes in joint position.

Kinematics: Kinematics involves the study of the size, sequencing, and timing of movement, without reference to the forces that cause or result from the motion.

Microsoft Xbox 360: The second video game console developed by and produced for Microsoft and the successor to the Xbox, a seventh generation videogame console which integrates Kinect, which allows the players to interact with the Xbox 360 without the need to touch a game controller, through a natural user interface using gestures and spoken commands.

Power analysis: A process that allows deciding: (a) how large a sample is needed to enable accurate statistical judgment and (b) calculate the minimum effect size that is likely to be detected in a study using a given sample size.

Exergame user research: It focuses on understanding user behaviors, needs, and motivations through observation techniques, task analysis, and other feedback methodologies.

Chapter 5

Muscle activation and coordination patterns during swimming exergame.

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Abstract

The effects of playing intensity on the activation patterns of upper-limbs' muscles during a sport exergame were investigated. Twenty male students played bouts of swimming exergame. Surface EMG of BB, TB, LD, UT, and ES were recorded during normal and fast game play. Mean muscle activation, normalized to MVIC, ranged from 4.9 to 95.2 %MVIC and differed between normal and fast swimming for all techniques ($p < 0.05$), except for LD during backstroke. Selective behavior was observed between muscles after normalizing the %MVIC to playing velocity. Investigation of muscular coordination showed in the fast mode, subjects completed the different phases of each cycle faster, which might stress some muscles more. These differences are also likely to happen in the early stages of play before players understand the game mechanics. Such evaluations might help in balancing activation of different muscles, offering safe and meaningful experiences.

Keywords: Virtual swimming; Surface electromyography; Kinematics; Exergame

Introduction

Computer games and particularly, exergames, are more and more popular. Game user experience (UX) evaluation methods commonly include questionnaires, video analysis, and interviews that require extensive training and come with their limitations (Fulton & Medlock, 2003; Lazzaro, 2004). These methods might be influenced by physiological constraints, which may be related to the actual playing experience. EMG related studies try to capture the emotional and physical reactions to game events (Mekler, 2014), which could be used to control the movements in computer games by appropriate selective muscle recruitment (Rios et al., 2013) or to measure unconscious emotional expressions; for example, increased activation of zygomaticus major is related to positive, and corrugator supercilii muscles to negative emotions (Witvliet & Vrana, 1995).

Exergames provide ample opportunities to play virtual sports aiming to increase PA levels and also to improve motor skills and performance capabilities (Dörrfuß et al., 2008; Wankel, 1993). Previous research confirmed that muscle activation of the neck and upper limbs while exergaming are higher than during sedentary games (Lui et al., 2014) and compared to computer counterparts, subjects have higher EMG responses when playing against a human opponent (Ravaja et al., 2006). While earlier studies provided convincing results regarding increased EE compared to sedentary gaming (Lanningham-Foster et al., 2006), later studies showed that as players gain experience, there are chances of low-effort playing by performing surrogate movements without activating the intended muscles while acquiring similar results (Converse et al., 2013). Moreover, as different types of feedback, competitiveness, and learning effects may contribute to exergame engagement (Lui et al., 2014), rapid responses of EMG have become a proper objective tool in recognition of players' preferable actions and might be useful in scenario development of video games (Gilroy et al., 2012).

While challenges in sedentary games are usually controlled by adjusting the complexity of mental tasks, employing physical in-game challenges can be unique characteristics of exergame design. It has been reported that subjects who used a video game to perform an exercise task did not have different muscle activation levels compared to those who performed the same activity without visual feedback (da Silva et al., 2015; Zaitsu et al., 2014). While real-world sport activities may usually generate higher muscle activation compared to virtual equivalents, EMG profiling can be used to make sport exergames closer to real activities (Crowther et al., 2015). With higher exergame engagement, muscle activation levels also increase (Zimmerli et al., 2013; Lui et al., 2014), and speed-based exergames might be employed to create physical demand and to avoid boredom when players' engagements diminish.

Although these low-cost and commercially available gaming platforms look promising, still little is known about skeletal muscle activation during exergame play. Concerns regarding long-time computer/video game use, repetitive movements, and musculoskeletal disorders, such as neck and shoulder pain exist (de Wall et al., 1992). With the introduction of exergames to other domains (e.g. rehabilitation) and due to abnormal movement patterns and different cognitive and sensory tasks, specific game design using EMG patterns seems to be necessary (Gatica-Rojas & Méndez-Rebolledo, 2014). While the chance of low-effort playing exists, it is also not clear if playing at higher speeds, lead to higher muscle activation or not. Moreover, few studies have been performed to determine muscle activation (relative to MVIC and with regard to movement velocity) of upper limbs and trunk during exergame playing. Therefore, the purpose of this study was to assess muscle activation levels elicited during a swimming exergame with two different playing velocities.

Methods

Participants

Twenty male college students (mean±SD 24.2±3.1 years (yr) of age, 177.6±8.1 m of height, and 73.3 ±10.4 kg of body mass), were recruited for this study. The procedures were approved by the local ethics committee (Process number: CEFADE 01/2013) and were according to the Declaration of Helsinki, imposing that, prior to testing, participants signed a written informed consent.

Procedures

Muscle activations of the BB, TB, UT, LD, and ES of the preferred limb (and side) were recorded using a Trigno™ wireless surface EMG apparatus (Delsys, USA) with a common mode rejection ratio of > 80 dB, input impedance of 10^{12} Ω, input range of 11 mV with a 16-bit amplifier, and sensitivity of 168 nV/bit at a sampling rate of 2000 Hz, for both MVIC and exergame trials. These muscles were chosen due to their importance in swimming (Martens et al., 2015) and hypothesized activation during this exergame (ES). Electrodes were placed according to SENIAM project (Hermens et al., 1999) and, for LD and BB, we adapted the procedures from Lehman et al. (2004). Placement sites were shaved (if necessary), lightly abraded, and cleaned with the alcohol swab to decrease skin impedance, in accordance with standard electromyographic procedures. EMG sensors employed four silver bipolar Ag/AgCl surface bar contacts (fixed inter-electrode distance of 1 cm and 5 x 1 mm contact area) for maximum signal detection and were placed on the skin using specially-designed 4-slot adhesive skin interface minimizing motion artifacts (Delsys, USA).

The Biodex System 4 (Biodex Medical Systems, NY) was used to obtain MVIC in accordance with the manufacturer instructions. The positioning of Biodex for BB was performed according to Gennisson et al. (2005), and for TB according to Lategan and Kruger (2007). For UT and LD, we followed Hong et al. (2012), and for ES, we used the procedures of Moreau et al. (2001). Three MVIC attempts of 10 s each were recorded for each muscle, with 2 s of ramping from rest to maximum contraction, sustained by 5 s, and more 3 s to progressively reduce the activation to resting levels, with a 1 min rest (Burden, 2008). While verbal encouragement was provided throughout the MVIC attempts, the mean highest value of the three attempts was used to normalize the trial data. To remove the effects of playing velocity, we divided the MVIC of filtered signal by the average velocity (Lui et al., 2014) during each gaming phase, using equation 5.1.

Equation 5.1. True normalized EMG = $\frac{\text{RMS expressed as \%MVIC}}{\text{Average velocity}}$

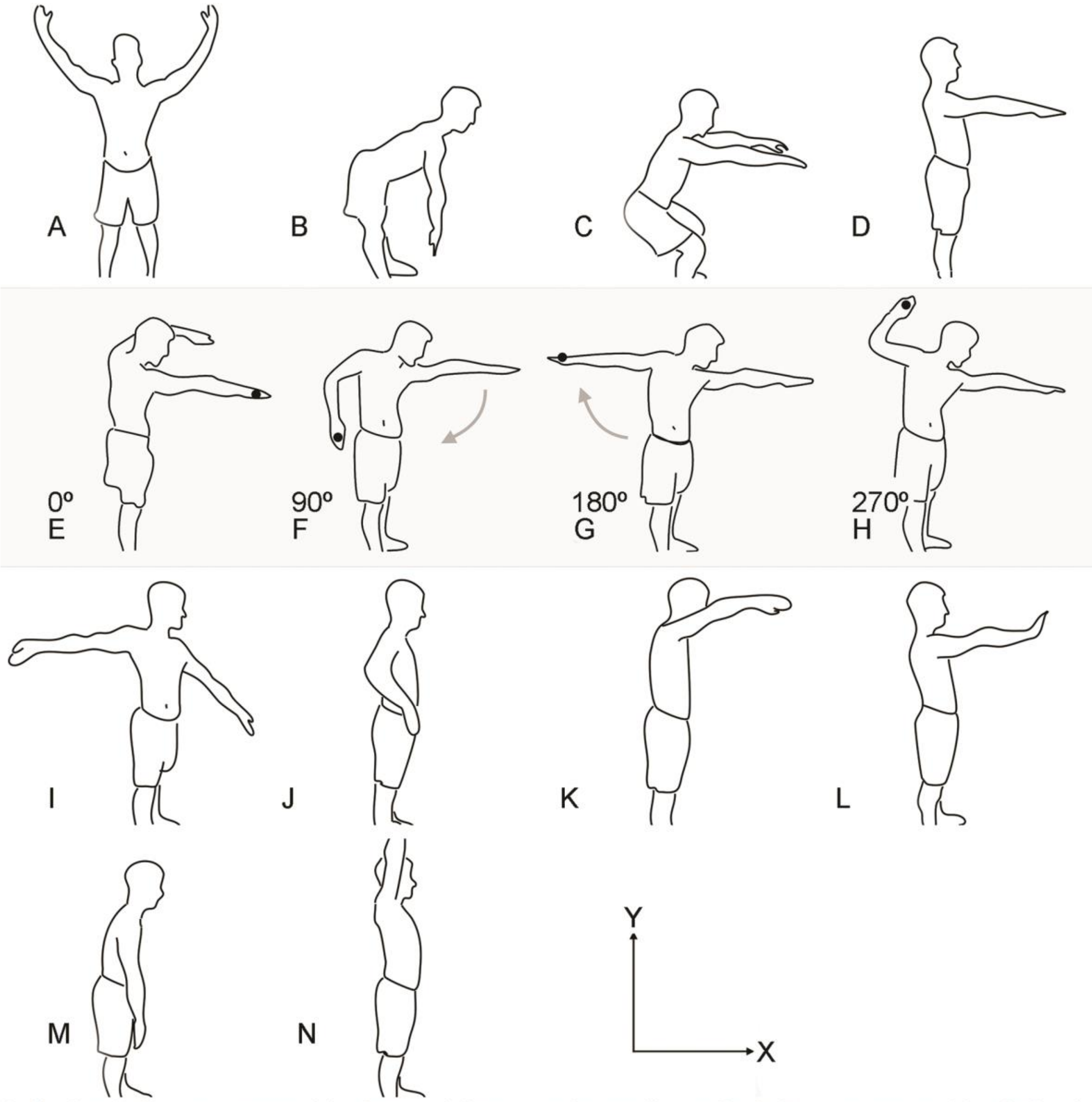
Three-dimensional kinematics were monitored at 200 Hz using a 12 camera motion capture system in acquisition software (Qualisys AB, Sweden). Twenty-two reflective markers were placed on the anatomical landmarks over the skin (cf. Rab et al., 2002): 7th cervical vertebrae, acromio-clavicular joints, lateral and medial epicondyles approximating elbow joints, wrist bar thumb side and pinkie side (radial styloid and ulnar styloid), dorsum of the hand just below the head of the 2nd and 5th metacarpal, inferior lower border of scapula bones, sacrum, sternum, anterior-superior, and posterior-superior aspects of iliac crest. The embedded local coordinate system was located at the proximal end (Y-axis pointing from posterior to anterior and Z-axis oriented longitudinally towards the proximal direction), and laboratory coordinate system was defined as posterior-anterior (+X), inferior-superior (+Y), and medial-lateral (+Z).

The following kinematic parameters were measured: (i) average velocity, measured on the hand's center (mid-way between 2nd and 5th metacarpal markers); (ii) elbow angle, was the angle between the shoulder-to-elbow and the elbow-to-wrist vectors; (iii) trunk rotation, as the angle change created by vector connecting the two shoulders' joint centers and vector connecting the superior markers of iliac crest in the static trial, projected onto the X,Z plane; and (iv) cycle time, with each cycle defined from the moment when the hand's center is at its maximum X coordinate (Figure 5.1 E) until it returns to the same position. An investigation of muscle coordination was also conducted using kinematics, and EMG signals were cut into cycles to provide activation sequences of selected muscles. In each swimming technique, cycles begin when the preferred hand center is at its maximum X coordinate (Figure 5.1 E; 0º), followed by the time when it is at lowest Y coordinate (Figure 5.1 F; 90º), continues to the lowest X coordinate (Figure 5.1 G; 180º), reaches the highest Y-coordinate (Figure 5.1 H; 270º), and ends up in the same maximum X coordinate to start a new cycle.

Swimming exergame (front crawl, backstroke, breaststroke, and butterfly; 100 m each) was played using Microsoft Xbox and Kinect (Michael Phelps: Push the Limit, 505 Games, Italy). The game play was divided into two phases of normal and fast intensity, and an on-screen continuous visual feedback bar provided information on the velocity of players' movements. The game console was connected to a 46" LED television, located 2.5 m in front of the subjects at 2 m height. Each event began with hype movements where subjects could move their body freely and gain extra points (Figure 5.1 A). During the front crawl, breaststroke, and butterfly events, subjects had to stand in front of Kinect and bend forward (Figure 5.1 B) and, after the visual command, they had to return to standing position with upper limbs at 90º of shoulder flexion (Figure 5.1 D). For the backstroke event, subjects had to hold their upper limbs in front with knees slightly bent (Figure 5.1 C) and then raise their upper limbs above their heads while extending their knees (Figure 5.1 N). Afterward, subjects had to swing their upper limbs (Figure 5.1 E – 5.1 H for front crawl, I for backstroke, J for breaststroke, and K for butterfly) to move the avatar inside the game. For starting the second lap, players had to extend their upper limb sharply (Figure 5.1 L). At the middle of the second lap, there was a possibility to swim as fast as possible called “Push the Limit.” At the end of the event, they had to drop their upper limbs (Figure 5.1 M) and then raise one to finish the race (Figure 5.1 N).

Data Analysis

The mean root mean square (RMS) values were normalized using MVIC and signal processing was performed using EMGworks® Analysis 4.0 (Delsys, USA). This included signal band pass filtering with a cut-off frequency between 20-450 Hz, full wave rectification, and RMS envelope calculation using a sliding window of 300 ms and overlap of 150 ms, for both MVIC and trial data. All values were expressed as mean±SD and outliers exceeding 2 SD from the mean were removed as noise, associated with motion artifacts, throughout the entire signal. Synced with EMG, kinematic data were exported to Visual3D motion analysis package (C-Motion, USA) to compute joint kinematics for phase plane diagram in different techniques. Following assessing equality of variance and normality of distribution, a paired t-test was used to determine if there is any difference between the five muscles in normal and fast swimming modes. IBM SPSS Statistics 20.0 (Chicago, USA) with an alpha level of 0.05 was used for all statistical analyses and Cohen’s *d* was employed to calculate the actual magnitude of the differences between normal and fast swimming for evaluated muscles as 0.2 = small, 0.5 = moderate, and 0.8 = large (Cohen, 1992).



A: Hyping; B: Preparatory position for crawl, breaststroke, and butterfly; C: Preparatory position for backstroke; D: Diving; E: Hand center marker at maximum X coordinate; F: Hand center market at minimum Y coordinate; G: Hand center marker at minimum X coordinate; H: Hand center market at maximum Y coordinate; I: Backstroke; J: Breaststroke; K: Butterfly; L: Return; M: Preparation for termination; N: Terminating the race.

Figure 5.1. Body positions during different events.

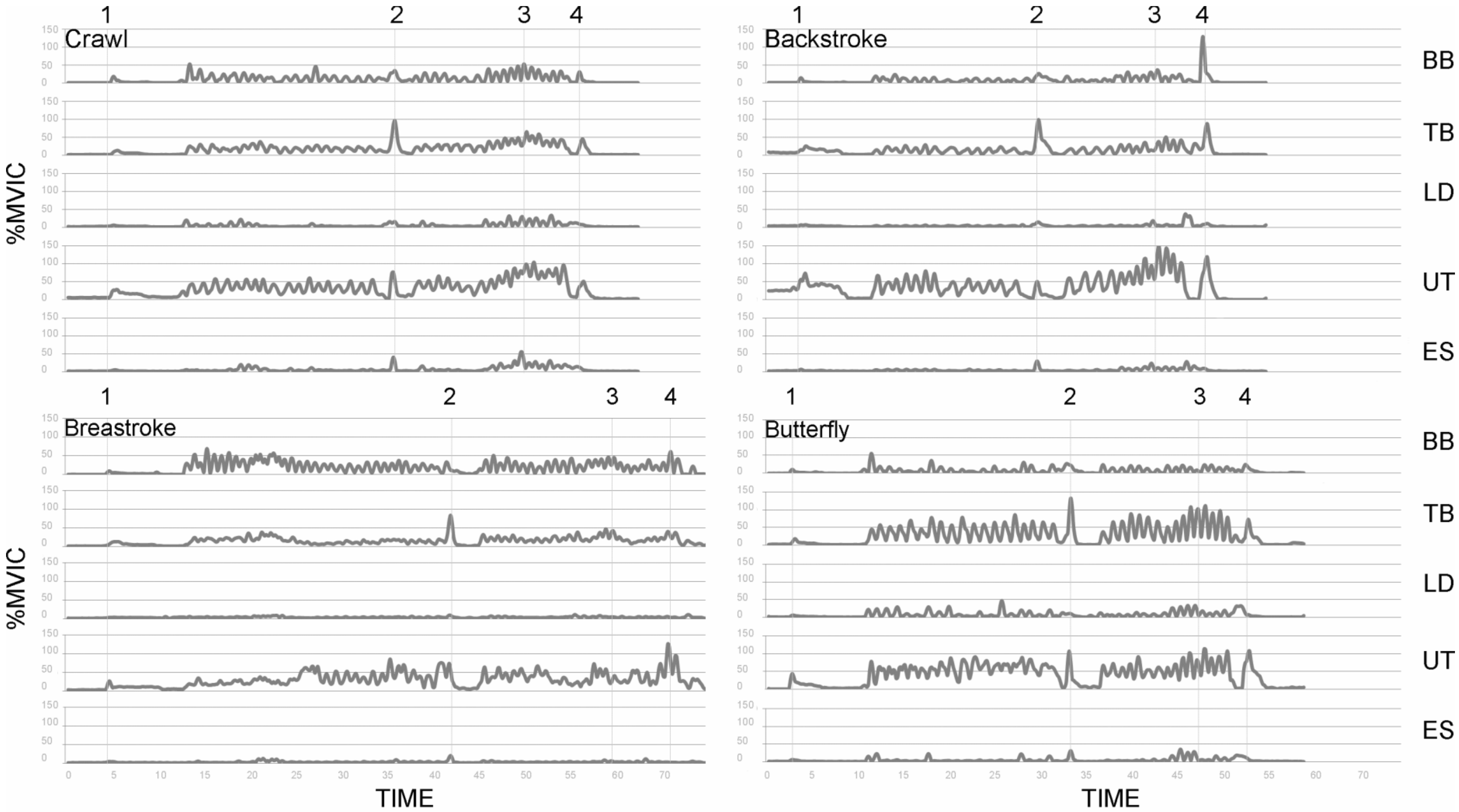
Results

Figure 5.2 presents a typical pattern of EMG in each swimming technique for one subject. There were no differences in cycle time and kinematics between different gaming velocities ($p > 0.05$; *d* average velocity = 1.6, *d* elbow angle, cycle time, and trunk rotation < 0.2) and the average of normalized EMG in the fast phase was higher than the slow phase. Mean±SD RMS EMG data was normalized to MVIC in Table 5.1, and to the average velocity in Table 5.2.

Table 5.1. EMG levels (normalized to %MVIC) while exergaming with two playing velocities for selected muscles.

Event	Velocity	BB	TB	LD	UT	ES
Crawl	Normal	10.0±4.5*	17.2±14.2*	12.3±12.8*	53.9±39.6*	7.9±3.9*
	Fast	19.1±7.9	24.5±12.7	31.5±30.9	80.65±55.1	18.2±10.2
Back-stroke	Normal	4.9±3.6*	18.7±14.8*	34.0±88.7	62.3±38.7*	6.8±5.1*
	Fast	9.1±6.1	28.9±29.4	71.5±218.8	95.2±57.9	13.6±7.8
Breast-stroke	Normal	13.5±15.7*	21.7±21.4*	13.1±11.6*	45.2±41.3*	6.1±4.6*
	Fast	22.7±16.9	31.0±30.1	24.9±19.8	59.4±42.9	10.3±8.0
Butterfly	Normal	8.4±16.6*	26.6±23.1*	19.4±25.2*	61.4±37.1*	6.8±4.7*
	Fast	13.6±19.5	40.2±35.7	39.7±49.5	82.7±46.8	21.8±16.6

*: Differences were observed between normal and fast swimming in muscle groups.



1: Start; 2: Return phase; 3: Fast swimming phase; 4: Terminating the race; Values of %MVIC ranges from 0 to 150% and each line represents 50% of muscle activation.

Figure 5.2. Time sequencing of EMG in different events normalized to %MVIC.

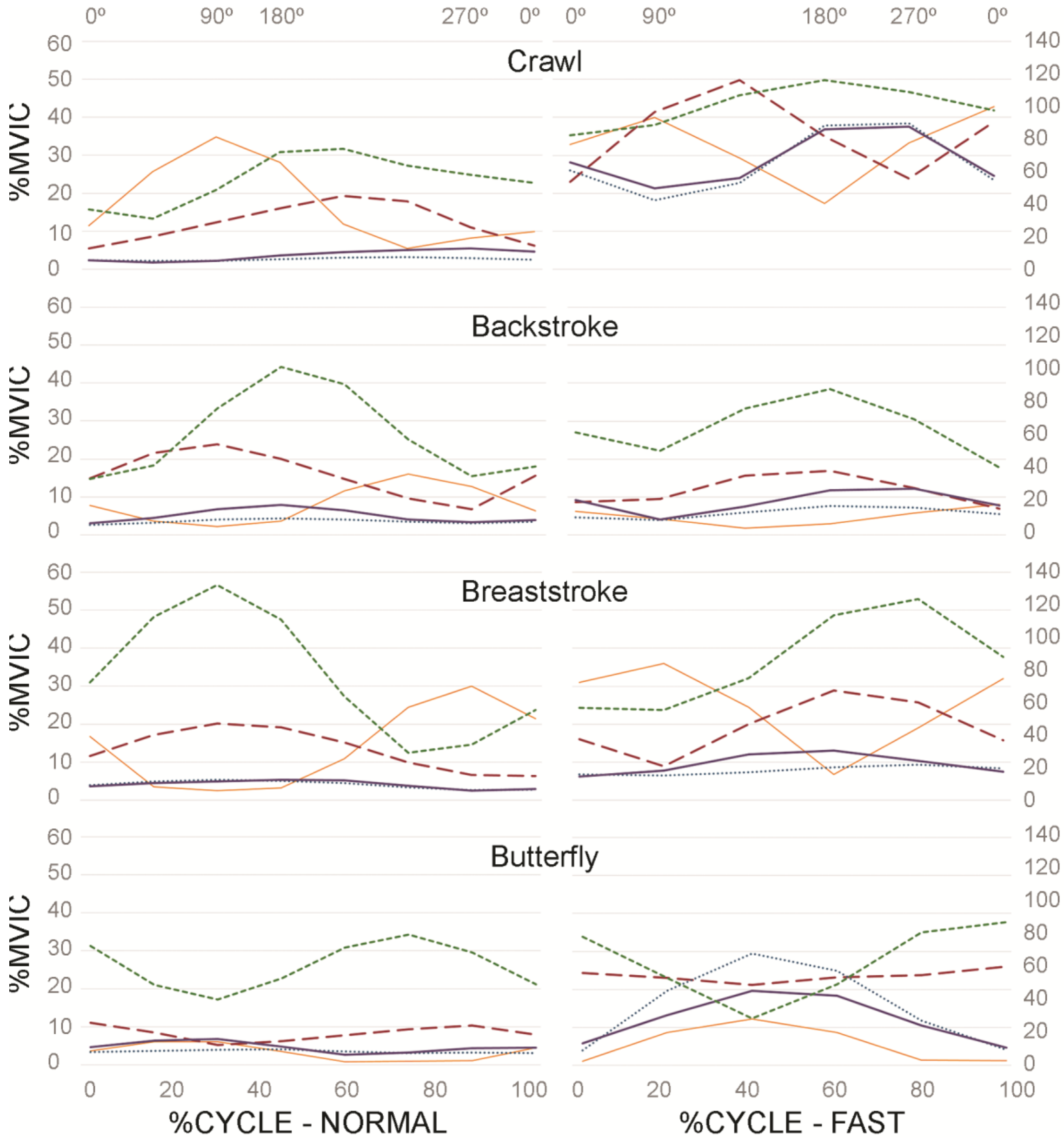
The paired t-test showed differences between normal and fast swimming between muscles for all techniques ($p < 0.05$; $d > 0.5$ during front crawl, $0.3 < d < 0.9$ during backstroke, and $0.3 < d < 0.6$ during breaststroke and butterfly), except in LD during backstroke ($p > 0.05$). However, after normalizing the %MVIC to gaming velocity, differences were observed in slow and fast gaming phases for LD ($t(19) = -3.008$, $p = 0.007$, $d = 0.4$) and ES ($t(19) = -3.645$, $p = 0.002$, $d = 0.6$) during crawl, BB ($t(19) = -2.312$, $p = 0.032$, $d = 0.3$) and ES ($t(19) = -5.105$, $p = 0.000$, $d = 0.3$) during backstroke, LD during breaststroke ($t(19) = -2.146$, $p = 0.045$, $d = 0.3$,), and BB ($t(19) = -4.491$, $p = 0.000$, $d = 0.2$), LD ($t(19) = -2.836$, $p = 0.011$, $d = 0.2$), and ES ($t(19) = -3.235$, $p = 0.004$, $d = 0.8$) during butterfly.

Table 5.2. %MVIC (normalized to playing velocity) during swimming exergame for selected muscles.

Event	Velocity	BB	TB	LD	UT	ES
Crawl	Normal	3.8±2.3	6.4±5.7	4.5±5.6*	19.8±14.3	2.9±1.7*
	Fast	4.5±2.2	5.8±3.3	7.8±9.1	19.2±13.4	4.3±2.3
Backstroke	Normal	1.3±1.0*	5.0±3.9	8.8±21.7	17.0±10.1	1.9±1.5*
	Fast	1.7±1.3	5.2±4.8	12.4±36.8	17.2±10.1	2.5±1.7
Breaststroke	Normal	6.3±6.3	9.6±8.0	5.9±4.8*	20.6±16.4	2.9±1.9
	Fast	7.6±5.9	9.8±8.6	7.9±6.7	18.6±11.6	3.4±2.9
Butterfly	Normal	1.8±3.9*	8.3±7.4	5.9±7.4*	19.4±11.2	2.1±1.3*
	Fast	2.9±4.6	8.4±7.4	19.4±11.2	17.4±10.4	4.5±3.7

*: Differences were observed between normal and fast swimming in muscles.

As shown by the investigation of muscular coordination in figure 5.3, UT activation was higher in backstroke compared to other events where expressive shoulder flexion/rotation is required, and participants were completing the second half of the movement cycle (180º to 0º) in a shorter time.



— BB; -- TB; ···· LD; — UT; -- ES; 0º: Hand center at maximum X coordinate, 90º: Lowest Y coordinate, 180º: lowest X coordinate, 270º: Highest Y-coordinate; Right side scales are attributed to UT activation (0 to 140% MVIC).

Figure 5.3. EMG activation patterns in one cycle during normal and fast gaming in different swimming techniques based on the position of the preferred upper limb.

Discussion

The main purpose of this study was to assess muscle activation levels during a swimming exergame with two different playing velocities. While results showed higher activation during fast swimming in all swimming techniques, differences were observed for LD and ES during the crawl, BB and ES during backstroke, LD during breaststroke, and BB, LD, and ES during butterfly when %MVIC was normalized to playing velocity. Our results confirm previous research which observed that muscle activation during sport exergames are higher than during sedentary video gaming. However, during playing out of the water, gravity is the only relevant resistance participants confront, affecting the movements as they lift their upper limbs. Compared to other muscles, activation of ES was low because the game requires dynamic movements of the upper body and after some time, players switch from technical playing (real-swimming movements) to pragmatic game play, facing the screen more while reducing the movements of trunk muscles (Park et al., 2014). After normalization of EMG to %MVIC, differences were observed between normal and fast swimming but only moderate to large effect sizes were observed during front crawl event, meaning that there is a trivial chance of observing different activation between different muscles during front crawl slow and fast swimming. This might have happened as front crawl was the first event tested and as subjects have not understood the game mechanics, they were trying to swim and physically exert as close as possible to real swimming.

During the front crawl, BB (elbow flexor) begins to contract at the start of 0º, and with hands rotating inwards and facing down, LD assists in lowering the hands. Due to lack of applied forces and as most of the work is done by gravity, the activation of LD is low. TB also helps to lower the upper limb from 0º to 90º bringing the hand backward and upward. From the middle of 0º to 90º, UT starts to be active, lifting and stabilizing the upper limbs similar to propulsive and recovery phases of real swimming (0º to 90º and 180º to 270º). From 90º, activation of ES is concurrent with the rotation of the body to bring the upper limbs backward. As players were mostly watching the screen avoiding the rotation of the body, this core stabilizer acts as a link between upper limbs and lower limbs. During fast swimming, as subjects were switching from 0º to 90º in a shorter time, they were using LD and ES intentionally more while rotating their body, leading to higher activation.

During backstroke, activations of TB with UT bring the players' extended upper limbs upwards, which follows by the LD activation in a virtual catch phase, bringing the hand lower and backward. Elbow flexor (BB) begins its activation as it is lowering, assisting in bringing the upper limb down before transiting into a new cycle (middle of 90º to 0º) placing a high demand on TB during the last portion of propulsive phase. During the fast swimming, subjects were returning from 180º to 90º in a shorter time, leading to higher ES activity and passively returning the upper limb forward (using gravity), causing lower activation compared to normal swimming. During breaststroke, movements start as upper limbs are held in front of the player. LD joins in and pulls the arm and hand into the midline of the body and from 90º to 180º and with the help of paraspinal muscles (including ES), the player goes forward and upward. Flexion at the elbow brings the hands to the middle of the body which is partially carried out by BB allowing shoulder joint flexion. Extension of the elbow in the middle of 270º and 0º brings the arms forward to their elongated position. While body roll does not exist in this technique, core-stabilizing muscles are important in linking the movement patterns of upper and lower extremities. Higher activation of LD during fast swimming was predictable, as players were switching from 180º to 0º in shorter times, requiring lowering upper arm (elbow) faster compared to normal swimming.

During butterfly and at 0º, players start the propulsive portion of the technique, and due to lack of forces, the activation of BB (elbow flexor) remains low, most of the propulsion is done by gravity, and LD activation acts as the primary mover. From 90º to 180º, the BB activation increases (pull phase) and after 180º, TB starts to be active while extending the arms. This extension of TB is accompanied with the activation of UT, lifting the arms and bringing them upwards and forward. In the middle of 270º and 0º, the activation of UT stops, allowing the gravity to continue lowering the arms. Similar to breaststroke, butterfly lacks the body roll, the ES activation happens only from 0º to 90º bringing the entire upper torso down. Activation of UT is important from 180º to 270º, helping to reposition the arms and linking the movements of upper and lower extremities and bringing upper torsi up and down. During normal swimming, players were mostly following real swimming movements while during the fast phase, they changed their pattern to simply rotating their upper limbs, resulting in higher activation of BB, ES, and LD compared to normal swimming.

Although sport exergames may not produce as much muscle activation as real activity (Zimmerli et al., 2013), such activities might still benefit participants to develop muscular endurance (McGill, 2001), especially when participation in real sport is not possible or practical due to disability, fear, or injury. Rios et al. (2013) showed an increase of 35 to over 500% in MVIC of wrist flexors and extensors over time in their neurogame therapy. While in our game, levels of muscle activation were lower than MVIC, repetitive strain injuries might still be taken into account when games are played excessively (Damiano, 2009). To prevent significant learning that might lead to activity reduction, variety and complexity should also be considered in the design phase (Zannatha et al., 2013). Moreover, there were several times where subjects stopped their movements completely; namely following virtual diving, and before starting the second lap, as subjects were seeing themselves from an underwater perspective performing the actions. The visual feedback bar was also acting as a controlling tool to prevent players from swimming too fast. Measuring these events during the design phase could provide information on how different players interact with games and could be utilized to maximize pleasure, to prolong the activity and retain the challenge, to balance activity-recovery periods, and prevent the early occurrence of fatigue.

Limitations

We acknowledge the limitations of this study. Although standard adhesive tapes were used for EMG electrodes, there was still the possibility of having motion artifacts on UT involving lots of rotational movements. Several studies have used the amplitude of raw EMG which might be justifiable in relative effects of short-term interventions but lack validity when comparing individuals between groups, different testing sessions, or both (Mathiassen et al., 1995). While RMS was previously used to represent the amplitude of EMG (Li et al., 2014), we used MVIC to normalize the percentage of muscle activation of subjects, relative to their maximum effort. However, it should be noted that acquiring EMG is a relatively time-consuming task and long game evaluation sessions might not be tolerable for some participants.

Conclusions

As shown by our results, EMG responses are dependent on playing velocity, and game designers might use these results to make their games more physically challenging and to use different strategies to encourage players to exert more. Moreover, with lower muscle activation compared to real swimming, physical educators might use the game to teach basic movements of real swimming and to participants (e.g. children) who are in the beginning of learning swimming. As exergames might also be used in clinical treatments (e.g. rehabilitation), it is important to know the amount of muscle activation in different players. It is also understandable that different players with different levels of experience have different levels of muscle activations, even if the platform does not allow technical game play.

Conflict of Interest

None declared.

Chapter 6

Energy systems contributions and time-motion analysis of swimming exergame.

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Abstract

We aimed to measure and compare the aerobic and anaerobic energy systems contributions and the activity profiles of forty participants, with different experience and gender, playing bouts of swimming exergame, using Xbox and Kinect. Oxygen uptake was recorded during exercise and [La^-] was collected immediately after performing each swimming technique and after the game. Participants' game plays were also filmed, divided into different phases and tagged as active or inactive. Total playing time (TPT), effective playing time (EPT), resting time (RT) and effort to rest ratio (E:R) were measured using video analysis. Lactate concentrations were 2.6±1.1 mmol.l-1, EE was 105.9±34.6 kJ, and anaerobic lactic pathway accounted for 8.9±5.6% of total EE, with no differences between performing groups ($p > 0.05$). Players were active 56.9±8.1% of total time, and E:R was 1.3±0.3. Experienced players had lower TPT (743 vs. 844 s), EPT (413 vs. 495 s) and mean rank E:R (17.7 vs. 24.6) compared to their novice counterparts ($p < 0.05$). Data suggest that the game platform does not allow considerable physiologic differences between different players and, despite lower levels of activity compared to real sport, both aerobic and anaerobic energy systems should be considered during game play.

Keywords: activity profile, lactate, energy cost, time-motion analysis, performance, effort to rest ratio

Introduction

Higher screen times (e.g. playing video games) are associated with PinA (Christofaro et al., 2015), and interventions to discourage their use are usually unsuccessful because players value these activities (Timperio et al. 2004). Besides predicting parameters for increasing PA levels, playing sport video games are associated with real sports participation among adolescents (Adachi and Willoughby, 2015; Ballard et al., 2009). Newer generations of video games (exergames) also provide opportunities for low to moderate (and sometimes large) EE (Bailey and McInnis, 2011; Bronner et al., 2013; Peng et al., 2011). Exergames are enjoyable, relatively low cost and have group-play modes that make them potential tools in combatting common barriers to exercise and sport (Jenney et al., 2013). Mixed with traditional means of performing PA, exergames have also been shown to increase exercise satisfaction in obese children and offer alternatives for unmotivated participants to exercise regularly (Finco et al., 2015), while having similar physiological responses (Lisón et al., 2015).

Depending on the video game type and difficulty, exertion levels vary, and higher PA intensities were observed when whole-body is involved during exergame play (Dutta and Pereira, 2015; Graves et al., 2008; Wu et al., 2015). Although HR, the rate of perceived exertion (RPE), movement monitoring and $\dot{V}O_2$ are among popular intensity measurements (Gao et al., 2015), a new methodology tried to estimate metabolic energy cost using algorithmic models (Nathan et al., 2015). There are also mixed results regarding the effects of experience and gender on EE, with evidence that prior gaming experience does not affect mean HR, but session RPE and peak HR were higher in novice players (Kraft et al., 2014). While it was reported that gaming experience results in higher EE and $\dot{V}O_2$ (Bonetti et al., 2010; Sell, 2008), others studies showed that prior experience and resting HR do not affect EE during sport exergame play (Graves et al., 2008; White et al., 2011; Wu et al., 2015). In addition, gender has been shown not to affect EE during exergaming among adults (Lanningham-Foster et al., 2009; Miyachi et al., 2010), but others suggested that male players burn more energy (Graves et al., 2008; Howe et al., 2015; Sit et al., 2010) and have higher $\dot{V}O_2$ and lower RPE compared to their female counterparts (Graf et al., 2009). It was also shown that although playing time and number of playing bouts do not differ; boys play exergames more actively than girls (Lam et al., 2011).

When playing exergames at moderate exercise intensity, and according to ACSM guidelines for health and fitness, aerobic energy pathway is believed to be the primary energy source (Sween et al., 2014), but measuring only $\dot{V}O_2$ may neglect the role of glycolysis in total EE measurements (Sousa et al., 2014). Despite previous research reported [La^-] for an upper-body exergame (boxing) to be 1.8±0.8 $mmol.l^{-1}$, and a lower-body computer game to be 2.4±1.5 $mmol.l^{-1}$ (Jordan et al., 2011), it was never considered in the assessment of EE. This consideration is important as sports exergames are meant to replicate real sports and their physiological demands, which during its design phase might ensure a more meaningful experience. Moreover, as many exergame platforms provide feedback on EE estimation based on specific algorithms, considering the anaerobic energy pathway might be useful in improving its accuracy (Kim et al., 2013; Tripette et al., 2014).

To measure a particular aspect of performance, researchers may use time-motion analysis as an indirect method for estimating physiological stress, particularly by dividing the game into sub-activities (Nilsson et al., 2002). This objective assessment of exergames could be used when normal physiological measurements are intrusive (Hughes and Franks, 2004) and, as performing a short effort activity requires using a different metabolic pathway compared to longer activities (Gastin, 2001), it may provide information on including the right energy system as well. Moreover, as different players might use strategies to exert less while achieving similar results (Soltani et al., 2016), activity profiles might also be used to detect these behaviors. Since no research regarding the relative contribution of anaerobic energy systems to total EE of exergame playing is conducted, the purpose of this study was to characterize the total energy demands (aerobic and aerobic) and activity profiles during a swimming exergame. Also, the physiological demands of groups with different experience and gender were compared. It was hypothesized that experienced players, non-real swimmers, and female players would have lower physiological characteristics and lower activity time during the game play.

Methods

Forty subjects (mean±standard deviation age 23.8±4.4 yrs, height 174.0±7.1 cm, body mass 71.9±11.2 kg) volunteered to participate in the study, which was approved by the local ethics committee (CEFADE 01/2013) and performed according to the Declaration of Helsinki. Subjects were asked to avoid strenuous activity and smoking 24 h before the testing session, to drink water liberally and to refrain from consuming alcohol, caffeine, and food, at least 2 h before their participation. Participants who had played this game before were considered as experienced and those who knew, at least, two conventional swimming techniques were considered as swimmers. All subjects provided their informed consents before participation in the study. Table 6.1 shows the demographic and anthropometric characteristics of each participant within each performing group.

Table 6.1. Demographic and anthropometric characteristics of the subjects.

	Swimming Experience		Exergame Experience		Gender	
	Y (n = 16)	N (n = 24)	Y (n = 24)	N (n = 16)	M (n = 31)	F (n = 9)
Age	24.1±4.9	23.7±4.2	24.3±5.1	23.1±3.2	23.3±3.7	25.5±6.3
Height (cm)	173.9±8.3	174.0±6.3	173.5±7.2	174.7±7.0	176.2±5.8	166.1±5.1
Mass (kg)	71.6±11.4	72.0±11.2	71.5±9.7	72.4±13.4	74.6±1.7	62.4±6.8

Y: Experienced; N: Novice; M: Male; F: Female; n: Number;

Procedure

The exercise task was a swimming exergame designed for Microsoft® Xbox 360 and Kinect offering four competitive swimming techniques (Michael Phelps: Push the Limit, 505 Games, Milan, Italy). After arriving at the laboratory, participants got familiar with the device through navigating the menus and exploring different options. Subjects had to stand in front of the Kinect sensor and move their upper-body according to front crawl, backstroke, breaststroke and butterfly swimming techniques to move the avatar inside the game. Each 100 m event was controlled by an on-screen visual feedback, preventing players from swimming too fast or too slow and, in the middle of the second 50 m lap, there was a possibility of swimming as fast as possible (Push the Limit – PTL). If players swam with a constant speed, they could reserve energy (points) on a so-called energy bar to use later during PTL.

Oxygen uptake at rest ($\dot{V}O_{2rest}$) and heart rate at rest (HR_{rest}) values were obtained and, to avoid varying work rate increments leading to relevant differences in [La^-], the order of events and game profiles were equal for all participants (Foxdal et al., 1994). Breath by breath (b x b) $\dot{V}O_2$ was measured using a portable telemetric gas analyser (K4b^2, Cosmed, Italy) and capillary [La^-] samples (25 µl) were obtained from the earlobe (Lactate Pro, Arkay Inc, Japan) at rest ([La^-]$_{rest}$), immediately after completion of each swimming technique and following the game play (3, 5, 7 min). The difference in lactate accumulation after and before activity ([La^-]$_{net}$) was measured as the differences between [La^-] at the end of the last event and [La^-]$_{rest}$, allowing estimating the partial contribution of anaerobic energy pathway. RPE was administered using OMNI Scale of Perceived Exertion (0-10) immediately after each swimming technique (Irving et al., 2006).

Data Analysis

$\dot{V}O_2$ data were verified, and irregular values were deleted from the analysis (considering only values in-between mean±4SD). Then $\dot{V}O_2$ recordings were smoothed using a 3-breath moving average and time-averaged at 5 s intervals (Sousa et al., 2014). Peak oxygen uptake ($\dot{V}O_{2peak}$) during the exercise was recorded, and aerobic energy contribution was calculated from the time integral of net $\dot{V}O_2$ versus time relationship (Sousa et al., 2014). The anaerobic lactic contribution (AnL) was calculated using Equation 6.1.

Equation 6.1. $AnL = \beta \times [La^-]_{net} \times M$

where: $[La^-]_{net}$ is the difference in lactate accumulation after and before activity, β is the energy equivalent of [La^-] accumulation (2.7 $ml.O_2.mM^{-1}.kg^{-1}$, di Prampero et al., 1978) and M is the mass of the subject. To express the EE in kJ during aerobic and anaerobic lactic energy contributions, an energy equivalent of 20.9 $kJ.l.O_2^{-1}$ was assumed (Figueiredo et al., 2011). To control the effects of oxygen demands and duration of each technique, we normalized $\dot{V}O_2$ responses to the differences of oxygen uptake at rest ($\dot{V}O_{2rest}$) and $\dot{V}O_{2peak}$, and time was expressed in percentages as the duration of each technique. Maximum HR was also measured during the game play.

Each player was filmed during the activity with a digital camcorder (Sony® DCR-HC42E, Japan) mounted on a tripod positioned ~ 2 m behind the players, covering both performers and the TV screen. Video recordings were divided and tagged as active and rest (inactive) to an accuracy of 1 s, based on Table 6.2, using a video edit software (Movie Edit Pro, Magix AG, Germany). The beginning and end of each movement were marked, and the duration of each movement was measured, allowing calculating total playing time (TPT), effective playing time (EPT), resting time (RT) and effort to rest ratio (E:R).

Table 6.2. Coding front crawl technique during swimming exergame for notational analysis.

Phase	Tag	Description
Introduction	RT	Stepping in front of the sensor.
Shake to play	EPT	Shaking hand for the sensor to detect the player.
Profile selection	EPT	Players sign in with their preferences or as guests.
Position adjustment	RT	Visual feedback to ask the player to stand within the visibility of the Kinect.
Mode and technique	EPT	Selecting single player or multi player, and type of swimming technique.
Press start	EPT	Pressing start button.
Presentation	RT, Skip	Player watches a brief video instruction about how to play the game.
Loading	RT	Player waits for the game to be loaded.
Hype the crowd	RT, EPT, Skip	Players can move their body to cheer the audience and get extra points. In fact,
Start	EPT	Player bends forward with both hands in front. After seeing the audio-visual command, they extend their back and stand with their hands in front (In backstroke, the start includes bending the knees with holding hands in front, extending the knees, standing, and raising the hands up after the audio-visual command).
Swim	EPT	Swimming according to the technique.
Return	RT, EPT	Extending one arm after seeing the visual feedback to reach to an imaginary wall and return.
Swim	EPT	Continuing the swimming according to the technique.
Push the limit (PTL)	EPT	Player could swim without any feedback and as fast as possible.
End	EPT	Player drops both arms and raises one arm to terminate the race.
Continue to game	EPT	Player selects another technique.

RT: resting time; EPT: effective playing time; Skip: the player has the options to rest, play, or skip this part using auditory commands.

Statistical Analysis

Descriptive statistics were reported for all variables, and normality (Shapiro-Wilk) was checked. A one-way ANOVA was used to compare physiological and temporal parameters during each event and within performing groups and, in the case of violence of homogeneity of variance, alternative non-parametric statistics (Kruskal-Wallis H) were utilized. A three-way ANOVA was also used to determine the effect between three performing groups and their interaction effect on [La^-], EE, HR, and RPE. SPSS 23 (Chicago, IL) was employed, and the significance level was set at $P < 0.05$. An effect size was computed for each analysis using the eta-squared statistic (η^2) to assess the practical significance of findings. Cohen's guidelines of trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) was used to interpret the results (Cohen, 1992). Reproducibility of the time-motion analysis was established using Lin's Concordance Coefficient (Lawrence & Lin, 1989; Freelon, 2013; Steichen and Cox, 2002). Two subjects were randomly chosen and analyzed twice by the same researcher, and the technical error of measurement (TEM) for intra-evaluator test-retest was measured for the performance variables (rest and activity, Hopkins, 2000). To avoid retention of knowledge of the content, we conducted the retest analysis one month after the initial testing. TEM accuracy estimations are shown as 95% confidence limits using Equation 6.2 (Tanner and Gore, 2000).

Equation 6.2. Absolute TEM = $\sqrt{\frac{\sum d^2}{2n}}$

where: d is the deviations between the two measurements and n is the number of deviations. The absolute TEM is then transformed into relative TEM, to express the error in percentages, using Equation 6.3 (Perini et al., 2005), where: VAV is the variable average value (expressed as the sum of the two measurements divided by two).

Equation 6.3. Relative TEM = $\frac{\text{TEM}}{\text{VAV}} \times 100$

Results

For all subjects, $\dot{V}O_{2rest}$ of 4.9±1.1 ml.kg^{-1}.min^{-1}, $\dot{V}O_{2peak}$ of 25.7±6.0 ml.kg^{-1}.min^{-1}, $[La^-]_{rest}$ of 1.4±0.6 mmol.l^{-1}, HR_{rest} of 67.9±17.0 beats per minute (bpm), $\dot{V}O_{2peak}$ of 21.4±6.4 ml.kg^{-1}.min^{-1} during the front crawl, 20.72±5.43 during backstroke, 18.21±5.33 during breaststroke, and 18.66±6.44 during butterfly were recorded. An example of $\dot{V}O_2$ kinetics in Figure 6.1, relative $\dot{V}O_2$ in Figure 6.2, and values of physiological measurements in Table 6.3 were presented during a typical game session.

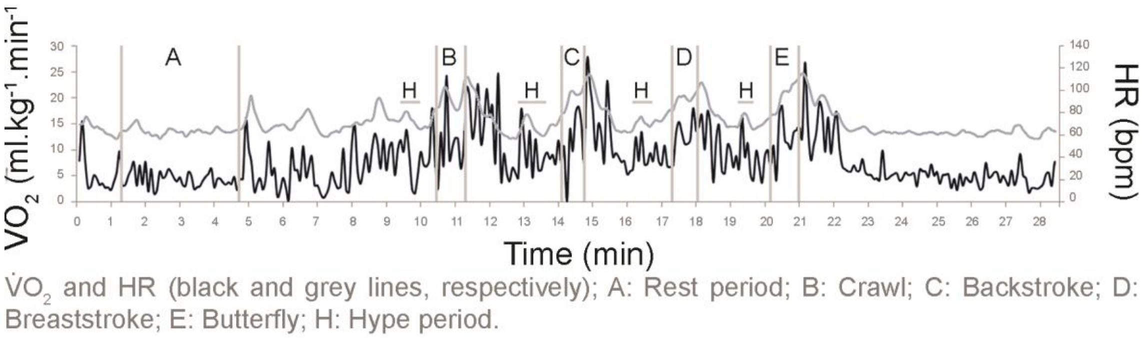


Figure 6.1. Typical $\dot{V}O_2$ and HR behavior during a bout of swimming exergame.

Mean $[La^-]$ during the activity was 2.6±1.1 mmol.l^{-1}, and it was not different between performing groups ($P > 0.05$, partial-$\eta^2 < 0.05$). Peak $[La^-]$ was 2.9±1.3 mmol.l^{-1} and occurred 3 min after the end of the game play, and no interaction was observed between swimming experience, game experience, and gender on $[La^-]$ changes ($P > 0.05$). Mean EE during the activity was 104.2±32.5 kJ (94.2±27.6 kJ aerobic plus 9.9±8.6 kJ anaerobic), with the lactic pathway accounting for 8.9±5.6% of total EE among all participants during the game play. EE within each performing group was not different, and there was no interaction between swimming experience, game experience, and gender on EE (partial-$\eta^2 < 0.09$, $P > 0.05$). Mean HR during the game play was 101.0±14.8 bpm, corresponding to 49.9±21.6% above the resting HR and 51.5±7.4% of maximum HR. HR was not different between performing groups, except for participants with real swimming experience who had higher values compared to non-swimmers during front crawl event ($F(1, 38) = 3.78$, partial-$\eta^2 = 0.09$, $P = 0.04$). There was no interaction between swimming experience, game experience and gender on HR during the game play and the four techniques ($P > 0.05$). Figure 6.1 illustrates a typical HR change throughout the game play. Mean RPE during the activity was

3.0±1.2 and was not different between performing groups (*P* > 0.05, partial-η^2 < 0.01). No interaction was observed between performing groups and RPE changes (*P* > 0.05).

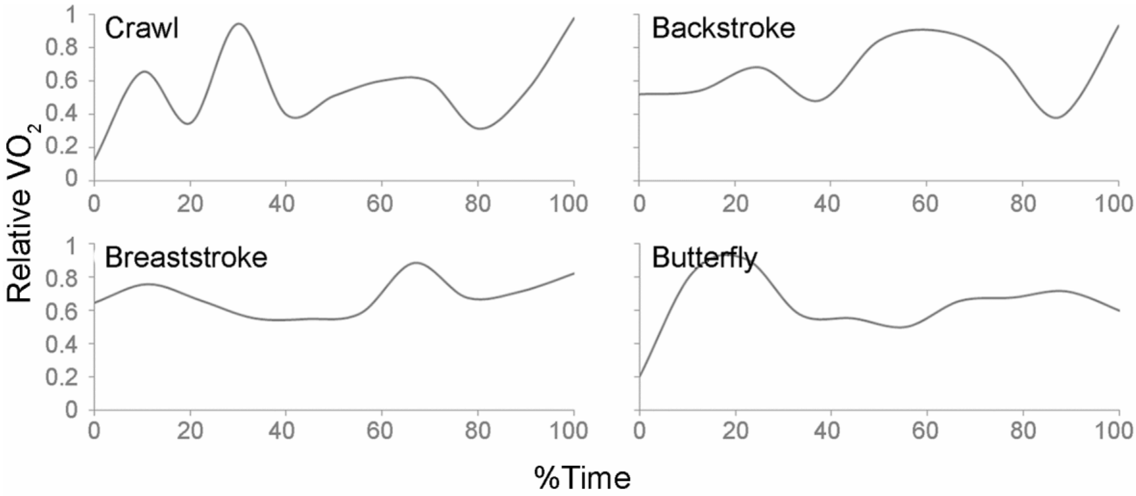


Figure 6.2. Player's $\dot{V}O_2$ normalized to the differences of $\dot{V}O_{2rest}$ and $\dot{V}O_{2peak}$ and time percentage for each technique.

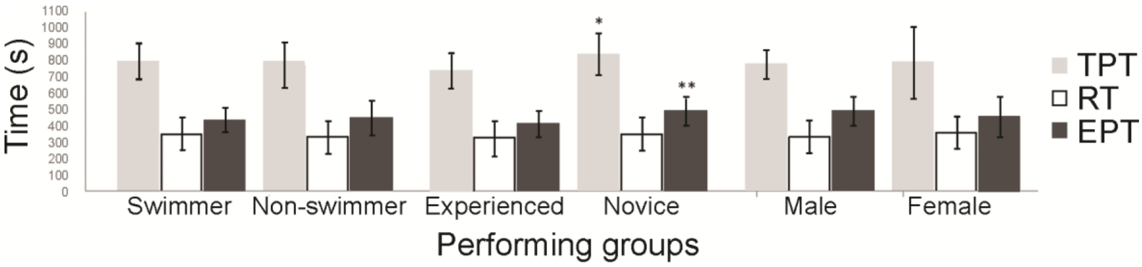
While a high intra-observer reliability of 0.96 was observed (McBride 2005), a second reliability check was also performed implementing TEM (with 95% confidence interval - CI) for each variable as follows: mean rest time of 287 s (95% CI = 267 to 296 s) and mean activity time of 441 s (95% CI = 421 to 450 s). The relative TEM was 3.5%, which is within the acceptable range (Duthie et al., 2003). Players were active 56.9±8.1% (range 42.7 to 85.1%) of the total time, rested 44.2±6.8% (range 27.7 to 64.7%) and had E:R of 1.3±0.3 during the game play. No differences were found between the performing groups (η^2 < 0.01, *P* > 0.05).

Table 6.3. Mean±SD physiological parameters and activity profiles in different exergame performing groups.

Variables		Swimming experience		Exergame experience		Gender	
		Swimmer	N-swimmer	Experienced	Novice	Male	Female
$[La^-]$ $(mmol.l^{-1})$	$[La^-]$ Activity	3.0±1.4	2.3±0.8	2.4±1.0	3.0±1.3	2.7±1.2	2.1±0.5
	Crawl	3.0±3.0	2.0±0.7	2.1±1.6	3.0±2.7	2.5±2.3	2.0±0.7
	Backstroke	2.7±1.0	2.1±0.8	2.2±0.9	2.7±1.0	2.5±1.0	1.9±0.6
	Breaststroke	3.0±0.9	2.5±0.6	2.6±0.7	3.0±0.9	2.8±0.8	2.3±0.5
	Butterfly	3.3±2.1	2.7±1.4	2.6±1.4	3.5±2.1	3.1±1.9	2.4±0.8
EE (kJ)	EE_{TOTAL}	113.4±40.4	97.4±24.1	95.3±24.4	119.3±39.5	111.0±33.5	82.2±15.7
	EE_{LAC}	12.9±11.6	7.8±5.0	7.9±6.7	13.5±10.6	11.3±9.4	5.7±2.7
	EE_{AER}	100.5±32.8	89.6±23.0	87.4±22.4	105.8±32.6	99.7±28.6	76.4±14.6
	Lactic (%)	10.2±6.6	8.0±4.8	8.0±5.5	10.5±5.8	9.6±6.2	6.8±2.7
	Aerobic (%)	89.7±6.6	91.9±4.8	91.9±5.5	89.4±5.8	90.3±6.2	93.0±2.7
HR (bpm)	HR-Total	94.1±18.3	85.5±12.5	88.4±16.9	89.8±13.5	88.3±15.6	91.2±15.4
	HR-Activity	105.7±15.7	97.9±13.9	99.0±13.1	104.0±17.5	99.2±14.7	107.3±15.1
	Crawl	105.9±17.9*	96.8±11.8	100.0±15.3	101.1±15.1	98.8±15.8	106.1±11.0
	Backstroke	105.8±13.8	103.0±16.6	101.6±12.0	108.0±19.4	102.1±14.9	111.1±16.3
	Breaststroke	105.4±17.8	99.3±16.9	96.9±15.0	104.5±19.6	98.2±17.0	106.0±17.3
	Butterfly	106.0±15.8	98.2±16.9	97.8±15.5	103.7±17.0	98.3±16.3	106.4±18.8
RPE	RPE Activity	2.9±1.1	3.0±1.2	2.8±1.2	3.2±1.2	2.9±1.2	3.2±1.4
	Crawl	2.6±1.3	2.0±1.2	2.1±1.3	2.4±1.2	2.2±1.3	2.2±1.3
	Backstroke	2.8±1.0	3.0±1.6	2.6±1.3	3.4±1.5	2.7±1.3	3.6±1.5
	Breaststroke	3.0±1.4	3.2±1.5	3.0±1.5	3.3±1.5	3.0±1.4	3.5±1.6
	Butterfly	3.4±1.7	4.0±1.5	3.6±1.7	3.9±1.3	3.8±1.5	3.6±1.9
Activity profile	Active (%)	54.5±4.4	58.5±9.5	55.8±8.6	58.6±7.1	56.4±7.2	58.5±10.9
	Rest (%)	44.3±5.0	44.0±7.8	45.5±7.2	42.0±5.4	43.3±6.1	47.0±8.3
	E:R	1.2±0.2	1.3±0.4	1.2±0.3	1.4±0.3	1.3±0.3	1.2±0.2

EE_{LAC}: Anaerobic energy contribution; EE_{AER}: Aerobic energy contribution; Lactic: Relative anaerobic lactic percentage; Aerobic: relative aerobic percentage; HR-Total: HR from the onset of activity until the end of the last technique; HR-Activity: mean HR during the four swimming events; RPE Activity: Mean RPE during the four swimming techniques; E:R: effort to rest ratio.

Figure 6.3 highlights the mean duration of TPT, RT and EPT within different performing groups. Previous exergame experience (experienced vs. novice) resulted in lower TPT (743 vs. 844 s; $F(1, 38) = 6.86$, partial-$\eta^2 = 0.15$, $P = 0.01$), EPT (413 vs. 495 s; $F(1, 38) = 8.70$, $\eta^2 = 0.18$, $P = 0.01$) and E:R (mean rank of 17.7 vs. 24.6; $\chi^2(1) = 3.422$, $P = 0.05$). TPT, RT and EPT were not different between swimmers vs. non-swimmers and males vs. females ($P > 0.05$) and no interaction between performing groups on TPT, RT and EPT was observed ($P > 0.05$).



TPT: Total playing time; RT: Rest time; EPT: Effective playing time; * and **: Differences between TPT and EPT).

Figure 6.3. Mean TPT, RT, and EPT in different performing groups.

Discussion

The aims of this study were to estimate different energy systems' contributions, to provide an activity profile of game play and to compare the results in different performing groups. Anaerobic energy production accounted for 8.9% of total energy production between all subjects and players were active 57% of total game play. Performing groups did not have different [La$^-$] and RPE, and mean HR during the crawl event was higher in participants with real swimming experience. Experienced players also had lower TPT, EPT, and E:R ratio compared to the novice players.

Our obtained relative $\dot{V}O_2$ and $\dot{V}O_{2peak}$ values were similar to the previous reports (Bronner et al., 2013; Siegel et al., 2009). However, it should be noted that these values are also dependent on game mechanics, duration and performing level. Higher $\dot{V}O_{2peak}$ values during front crawl might have occurred as it was the first technique and participants were trying to swim close to real swimming technique. Moreover, $\dot{V}O_{2peak}$ during front crawl was also lower than real swimming with full body and upper body (Barbosa et al., 2006; Holmér, 1974;

Ribeiro et al., 2014), which confirms previous findings comparing conventional exercise programs with virtual ones (Griffin et al., 2013; Taylor et al., 2014). Alternatively, the explanation regarding the lower $\dot{V}O_2$ during breaststroke might be related to lower range of motion of the upper limbs during exergame play (Sparrow and Newell, 1998). In general, as there were almost no forces applied on the body compared to in-water hydrostatic pressure, different responses were expectable.

Mean [La^-] in our study was higher than findings of Jordan et al. (2011) probably due to different game design, recruited muscles, type of platform, intensity and the duration of the game play. [La^-] values of performing groups were similar and low percentage of their variabilities, accounted by the different performing categories; Therefore, we reject our hypothesis stating that real swimmers, experienced and female players had lower [La^-] during the game play. This might have happened as the gaming platform detect different movement patterns of players similarly, and players may switch to pragmatic game play even after a short exposure to the game (Soltani et al., 2016).

As including the anaerobic energy pathway within total EE measurement provides a more complete and accurate measurement of energy (Capelli et al., 1998; Figueiredo et al., 2011), in the current study EE was calculated using both aerobic and anaerobic regimens. As participants had to use both upper limbs (involving higher muscle mass) during the game play, EE levels were higher than sports exergames using only one upper limb (e.g. tennis, bowling; Graves et al., 2008a) but lower than games incorporating both upper and lower limbs (Jordan et al. 2011) and real swimming (Ribeiro et al., 2014). Possible explanations are different design (incorporating different muscle groups), different EE measurement methodologies, different demands of gaming platform and efficient interaction with gaming platform (O'Donovan and Hussey, 2012). While many exergames raise EE above resting levels (Graf et al., 2009), our results also confirm that many sports exergames do not meet the recommendations of daily PA for children and adolescents (Graves et al., 2008a).

EE was similar between groups and the low percentage of its variability accounted by different performing groups. Contrary to the previous research attributing lower EE with the lack of experience (Bailey et al., 2011; Kraft et al., 2011; Sell et al., 2008), we found similar EE levels between novice and experienced players. This was also confirmed by similar activity profiles, which could mean that contrary to other platforms, the levels of low-effort playing are decreased. Higher EE in novice players might have also occurred because of longer game play, as they spent more time to complete the events. Moreover, players with real swimming experience might have put more effort swimming correctly at the beginning of their game play or during the first technique. Contrary to the previous research, in our study male and female players did not have different EE (Barkley et al., 2009; Epstein et al., 2007; Siegel et al., 2009) and HR (Graf et al., 2009). As the sensor could not detect delicate movements of real swimming and as soon as subjects recognized the game mechanics, they might have changed their movement patterns (Soltani et al., 2016), leading to similar physical exertion.

We also obtained higher values of HR compared to the previous study on Wii muscle conditioning and brisk walking (Graves et al., 2010). Previous research shows that although HR and RPE differ between real and exergame boxing, EE did not differ between the two conditions (Perusek et al., 2014), rejecting our hypothesis stating that real swimmers, experienced and female players had lower HR compared to their counterparts. RPE was not different within any performing groups, and the values were also lower compared to previous research in full-body and upper-body exergame (Whitehead et al., 2010). Moreover, our results suggest that the type of gaming platform (Xbox, Wii, etc.) does not lower psychological perception of exertion (Lisón et al., 2015; Moratt, 2012). Although novice players played the game for a longer time, RPE was not different than experienced players. This was consistent with previous research suggesting that immersive exergames may alter players' perception of game intensity resulting in longer game play (Lau et al., 2015). Therefore, we reject our hypothesis stating that real swimmers, experienced and female players had lower RPE than their peers.

The average effort to rest ratio in the current study was 1.3±0.3, showing that although players dedicated more time playing than resting, the results were not statistically different. Our active play values were also lower than previous study, ranging from 65-88% (Bronner et al., 2013). Possible reasons are lengthy waiting times between each technique and low activity times during each technique. While novice and experienced players did not differ in RT, experienced players spent less time playing with the game. This might have happened because the platform allows players to play pragmatically (less effort), and shorter time might be due to navigating faster through the menus and following game strategies in experienced players. Therefore, we reject our hypothesis that experienced players, real swimmers, and female players had higher RT compared to their peers.

As it may not be possible to reduce video game playing completely (Siegel et al., 2009), proper exergame design by which to meet the ACSM's recommendations might be used to increase PA levels. Such strategies could also help players with lower self-confidence, who prefer to exercise at home, seeking immediate satisfaction through selecting enjoyable activities while increasing the duration and quality of PA (Kraft et al., 2011). Software loading and menu selection have great effects on increasing workout times (Bronner et al., 2013) and by using auditory commands, using bigger icons and default settings, such timings could be shortened leading to an increase in effective game play. Moreover, HR seems to be the easiest parameters to be used for adjusting the intensity of exergames in the early stages of game development (Hoffmann et al., 2014; Sinclair et al., 2010). Moreover, as frequent exergame play may also provide a sense of healthy physical fitness, causing declined interest in the continuation of game play (Lai et al., 2012; Sun, 2012), these game evaluations could be used to design more challenging levels. Identification of work and rest intervals could provide relevant data on how to encourage players to expend more energy in a more realistic manner. Moreover, if the obtained effort to rest ratio, is compared with other games, it can potentially be used as a fitness index within exergames. We also have to highlight that tagging the activities using video-based time-motion analysis is moderately reliable (Platanou and Geladas, 2006). However, as subjective procedures like this come with lots of variation in quantifying the movements between different researchers, caution must be taken when applying these methods to other studies.

Conclusions

The results of this study are useful for user experience researchers, game designers and physical educators who want to apply exergame in their practice. We have quantified several physical and technical variables to explore the physical demands of exergame playing in more detail, which provides foundations for developing specific exergames. Our results showed that despite low levels of activity compared to real sport, both energy systems should be considered during EE measurements in exergames. Different performing groups did not respond to the game differently, which might suggest that the gaming platform does not allow technical game play. Moreover, the current investigation suggests using time-motion analysis during game design to increase the exercise to rest ratio. It is important to notice that playing style might influence the activity profiles, and if players learn the mechanics underlying exergames, this might affect the intensity levels as well. Future studies should try to understand the relationship of using different energy systems and total playing time during game play. Longitudinal studies are also needed to evaluate the effects of training on levels of EE.

Conflict of Interest

None declared.

Chapter 7

Does swimming exergame encourage players to participate in physical activity and real sport?

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Abstract

Sports exergames are accessible forms of PA which might help to convert sedentary screen time into active game play. The purpose of this study was to evaluate how game experience, usability, and enjoyment of a swimming exergame, affect future intentions of participation in PA and the real sport. Eighty college students played a swimming exergame using Xbox and Kinect. Enjoyment was measured using the short version of PACES, and two additional questions were used to measure future intentions of participation in PA and real swimming. Game usability was measured using System Usability Scale and playability aspects using Game Experience Questionnaire. Players were categorized based on gender, previous real swimming experience, and exergame experience. Mean usability score was 74.70±13.65, which is considered as good with high acceptability. Psychological measurements were not different between performing groups, but female players with real swimming and exergame experience enjoyed the game more ($p < 0.05$). Moreover, PA intentions did not change within performing groups, but swimming intentions were increased for all players. Designing games that provide a balance of challenge, immersion, and engagement is a difficult task. Our results suggest that interactions of physical exertion, platform usability, and players' skill levels should be considered for developing an effective intervention for increasing PA.

Keywords: Enjoyment; Game experience; System usability; Exercise.

Introduction

Current healthcare community recommends that adults should participate in at least 150 minutes of moderate PA per week (WHO, 2010). The stimulus for these suggestions arises from recent data indicating a higher prevalence of overweight youth in southern Europe (Janssen et al., 2005). Sedentary screen-based activities shape a significant part of leisure time, and strategies such as making sedentary activities dependent on exercise (Faith et al., 2001), using reinforcement to depress sedentary activities (Epstein, Paluch, & Raynor, 2001), and setting television "plans" (Ford, McDonald, Owens, & Robinson, 2002), might be used to decrease sedentary times. While traditional gaming is appealing to players (Ryan, Rigby, & Przybylski, 2006), there might be the possibility of promoting PA using exergames that employ players' body movements to interact with the games. Due to affordability and ease of use, exergames are accepted quickly by consumers of all ages. By increasing EE levels, previous studies have also suggested that exergames may provide opportunities to convert sedentary time into activity (Maddison et al., 2007).

Exergame Enjoyment

Environmental and psychological factors influence inactivity patterns (Jordan et al., 2006), and enjoyable interventions are needed to discourage PinA within home environments. Enjoyment can both predict and be an outcome of PA participation, and higher enjoyment might increase PA intention (Williams et al., 2006; Ruby et al., 2011). Enjoyment is also one of the reasons why people play video games and motivates them to continue playing (Lyons et al., 2014). Previous studies reported higher enjoyment for exergames compared to traditional forms of exercising (Perron et al., 2012; Thin, Hansen, & McEachen, 2011). Therefore, sport exergames might be potentially used as a bridge to increase activity and real sport participation intentions. Questionnaires such as PACES have been employed to measure exergame enjoyment. Previous data showed that experienced players enjoy exergames more than novice peers (Huang & Gao, 2013), and male players perceive exergame sessions to be more enjoyable than female counterparts (Sun, 2013).

Usability and Game Experience

To develop a reliable and engaging exergame, designers should complete several requirements. System Usability Scale (SUS) is a measurement of learning, control, and understanding a game, and higher SUS grade translates into an easier interaction between human, different games and menus, and various controllers and gaming platforms (Pinelle, Wong, & Stach, 2008). As shown by Sauro (2011), SUS can be applied to a wide range of domains regardless of technology. Usability in exergames is challenging because not only they should meet software expectations, but also they have to be fun, acceptable, and effective (Nawaz et al., 2015). It is particularly important when exergames are used in different age groups (Quiroga et al., 2009) and other serious domains, such as education and rehabilitation (Ijsselsteijn et al., 2007). For example, Uzor and Baillie (2014) conducted a 12-weeks exergame rehabilitation program and concluded that with higher SUS score, adherence and acceptance of patients are also greater. Moreover, it is also important to understand the relationship between general usability aspects of the software (game) and enjoyment (Bronner et al., 2015) and to explore how different players perceive the exergames (Marinelli & Rogers, 2014).

User experience (UX) deals with consumers' dynamic perceptions and responses of products and systems (Law et al., 2009) and is an important factor for game design and positioning of the problems. Game Experience Questionnaire (GEQ) consists of several components, including flow concept, a state in which there is a balance between the difficulty of the task and the skills that the performers possess (Csikszentmihalyi, 1991). With the occurrence of flow, players become immersed, ignoring the world around them (Brown & Cairns, 2004). Immersion is often associated with enjoyment (Sweetser & Wyeth, 2005). A state of deep involvement in the game is recognized as absorption (Agarwal and Karahana, 2000). Presence is also a psychological feeling of being in a virtual environment (Slater et al., 1994) and shows how engaged people are while playing video games (Schmierbach et al., 2012). Previous research has shown that higher feeling of presence is also related to enjoyable gaming experience (Jin, 2009) and skill levels do not affect game experience (Depping et al., 2016).

Gerling et al. (2011) used GEQ to study accessibility and usability of exergames in elderly, suggesting that enjoyment is not affected by age. While several attempts have been made to determine short-term physiological benefits of exergaming (Maddison et al., 2007), it is still not clear whether exergames increase PA levels. It is also important to determine whether variables such as usability and game experience influence future PA participation. Such comprehensive exergame taxonomy ensures an entertaining, and thus, an engaging game can be developed.

Future Intention of PA and Real Sport

Lack of time to exercise and perception of activity to be not enjoyable and convenient might be common reasons for the rapid decline in PA participation of young adults (VanKim et al., 2010). Studies have shown that the time dedicated to consuming media and play video games is usually accompanied by sedentary behavior (Calvert & Wilson, 2009). Although a recent study has shown that playing sedentary sport video games might have a predictive effect in real-sport participation (Adachi & Willoughby, 2016), traditional forms of media may not be suitable for providing behavioral change (Schooler et al., 1998). Moreover, it has been suggested that playing exergames might improve players' attitudes toward other forms of exercise (Van Nguyen et al., 2016) and therefore, it seems that virtual reality interventions might be more proper tools in targeting specific messages to a broad number of players (Fox, 2010). To our knowledge, there is no work documenting if playing certain virtual sports exergames can encourage players to participate in real related sport. It might also be possible, yet unknown, that virtual sports encourage players to participate in PA in the future which could predict if they have maintained behavior towards the PA or not.

Although exergames may seem more enjoyable that traditional video gaming, there is little evidence supporting adult's enjoyment and ease of use of sports exergames. Additionally, it is needed to understand whether gender, real-life sport, and exergame experience affect levels of enjoyment of such activities. It is also not clear whether exergaming encourages players to participate in more PA and real sports. The purpose of this study was to compare enjoyment, game usability and experience, and future intention of participation in PA and real-sport in players with different performing levels.

Materials and methods

Participants

Eighty healthy college students (21 female) aged 24.8±4.98 yrs participated in this study. Each participant signed an informed consent, approved by local ethical committee (Process No: CEFADE 01/2013), which was in agreement with the Declaration of Helsinki. Experienced gamers (n = 51) were those who played exergames once a week or more often and real-swimmers (n = 45) knew at least two swimming techniques (including front crawl).

Measures

Following the completion of the activity, the short version of PACES (sPACES) with a 7-point Likert scale, was used to measure the enjoyment (Dunton et al., 2009). Minor wording modifications were made to the items to ensure domain specificity; namely, we changed, some of the items to “when I was physically active playing the virtual swimming game during this study …” and also changed items to past tense (e.g., I disliked it). Both negative and positive statements were included to reduce acquiescence and calculation of internal consistency reliability score in this study was acceptable (α = 0.76, Nunnally, 1978).

Players’ game experiences were measured using GEQ (Brockmyer et al., 2009), with 19-items rated on a 5-point Likert scale ranging from 1 (not at all) to 5 (extremely). It has been used in several gaming studies and can accurately report game play experience. Game usability was assessed using SUS (Brooke, 1996), which consists of ten items and is used to derive a total usability score. We modified some items to make the scale more game-specific; namely, the word “system” was replaced with “game” and “use” with “play.” To elucidate the scores and make them more understandable, we converted SUS scores to grades using a scale defined by Bangor, Kortum, and Miller (2009), ranging from 0 to 100. Also, overall game quality (OR) was rated by each participant on a Likert Scale of 1 (worst quality) to 10 (excellent quality).

The following items – “If I had a chance, I would participate in PA later today” and “If I had a chance to participate in physical activity, I would choose swimming.” – were completed before and after participation in the study to measure the changes in the future intention of participation in physical activity and swimming (Dougall et al., 2011). The items were rated on a 7-point scale ranging from 1 (not likely at all) to 7 (very likely). This item has been used in previous research exploring future intentions (Xiang et al., 2003). A single-item intention measure of intention has been shown to be predictive of exercise behavior measured by both fitness testing and observations of engagement during PA classes with late adolescents (Greenockle et al., 1990).

Procedure

Feasibility of the questionnaires and procedures were pretested and refined with a pilot study of 10 participants who were not included in the main protocol. Upon arrival, subjects completed the two items measuring future intention in PA and swimming, and their previous exergame and real swimming experience. Procedures were explained (through video tutorial), and as subjects were also participating in other biophysical studies, they were fitted with other instruments. Subjects played with a swimming exergame designed for Microsoft Xbox (Michael Phelps: Push the Limit, 505 Games, Milan, Italy), where they had to stand in front of Kinect motion sensor and mimic the movements according to different techniques. At the end of game play, participants completed the SUS and GEQ questionnaires and answered the questions regarding PA and swimming intentions again.

Data Analysis

Descriptive data (mean±standard deviation – SD) were reported for all variables and equality of variance and linearity of variables were monitored. Negatively worded items of sPACES were reverse coded (Ni Mhurchu et al., 2008) and total enjoyment was recorded as the mean of 7 items. A two-way ANOVA with simple main effects analysis was used for enjoyment, SUS, GEQ, and overall quality of the game. Gender, prior real swimming, and exergame experience were considered as between-subject factors. To determine the relationships between enjoyment, usability, game experience, and PA and swimming intentions, Spearman's correlation coefficients were used. Split-plot ANOVA was used to analyze the changes in future PA and swimming intentions, incorporating both repeated measure effect (pre- and -post) as well as between group effect (male vs. female, swimmer vs. non-swimmer, and novice vs. experienced). Statistical significance was set to 0.05, and an effect size was computed for each analysis using Hedges' *g* to measure the practical significance of findings (Hedges & Olkin, 1985, p. 86). To interpret the *g* effect size, Cohen's guidelines of 0.2 = small, around 0.5 = medium, and above 0.8 = large, and for correlations, corresponding figures of 0.1, 0.3, and 0.5 were employed (Cohen, 1988).

Results

Descriptive statistics are reported in Table 7.1. A two-way ANOVA showed that there are no effects of gender, real swimming, and exergame experience on enjoyment, SUS, OR, and GEQ and its components ($p > 0.05$; $0.5 > g_{Hedges} > 0.003$). However, simple main effects analysis showed that female players with real swimming and exergame experience had higher enjoyment score (F (1, 72) = 4.436, $p = 0.04$). Overall SUS score was 74.70±13.65 and considered as good (grade scale of C) with high acceptability (Bangor, Kortum, & Miller, 2009). Four GEQ components are also presented in Table 7.2. PA intention for all subjects and within performing groups did not change ($p > 0.05$, $d_{Cohen} = -0.03$) but swimming intention increased for all subjects ($F(1, 79) = 18.46$; $p = 0.03$, $d_{Cohen} = 0.50$). However, the magnitude of the main effect was not contingent on gender, real swimming experience, and exergame experience ($p > 0.05$).

While there was low to moderate correlation between enjoyment and SUS (Spearman's ρ = 0.31) and enjoyment and overall rating (ρ = 0.43), there were strong relationships between PA intentions (ρ = 0.74) and swimming intentions (ρ = 0.49) before and after game play. SUS was also related to overall rating (ρ = 0.50) and swimming intentions after the game play (ρ = 0.25). There were also correlations between overall rating and GEQ (ρ = 0.35), all for $p < 0.05$. There was no correlation between presence and enjoyment and enjoyment and future intention in either PA or real swimming ($p > 0.05$).

Table 7.1. Descriptive statistics for psychological variables of performing groups.

		Before		After					
		PAint	SWIMint	PAint	SWIMint	ENJ	SUS%	OR	GEQ
Gen	M	4.85±1.33	2.41±1.26	4.81±1.37	3.17±1.76	5.89±0.97	73.92±13.38	7.80±1.44	2.80±0.67
	F	4.62±1.11	2.43±1.20	4.52±1.20	3.05±1.39	6.11±1.05	76.87±14.48	8.10±1.11	2.70±0.50
RSE	Y	4.84±1.18	2.82±1.30	4.82±1.07	3.53±1.60	5.99±0.80	75.53±12.32	7.74±1.57	2.83±0.72
	N	4.71±1.40	1.89±0.93	4.63±1.61	2.63±1.62	5.90±1.21	73.67±15.25	8.06±1.04	2.70±0.50
EE	Y	4.861.07	2.33±1.21	4.78±1.18	3.25±1.53	6.13±0.82	73.28±14.47	7.69±1.37	2.77±0.64
	N	4.66±1.58	2.55±1.29	4.66±1.56	2.93±1.88	5.64±1.19	77.14±11.95	8.21±1.31	2.77±0.62
Total		4.79±1.28	2.41±1.24	4.74±1.32	3.14±1.66	5.95±0.99	74.70±13.65	7.88±1.36	2.77±0.63

Gen: Gender; RSE: Real swimming experience; EE: Exergame experience; P: Performance; M: Male; F: Female; Y: Yes; N: No; PAint: Physical Activity intention; SWIMint: Swimming intention; ENJ: Enjoyment; SUS: System usability scale; OR: Overall rating; GEQ: Game experience questionnaire.

Table 7.2. GEQ components' scores between performing groups.

		Absorption	Flow	Presence	Immersion
Gen	M	2.23±0.71	2.79±0.67	3.20±0.78	3.35±1.18
	F	2.17±0.68	2.91±0.56	2.82±0.76	3.05±1.14
RSE	Y	2.21±0.74	2.87±0.72	3.14±0.85	3.38±1.26
	N	2.21±0.66	2.76±0.53	3.06±0.72	3.14±1.04
EE	Y	2.15±0.66	2.88±0.63	3.02±0.81	3.10±1.22
	N	2.32±0.76	2.72±0.66	3.25±0.74	3.57±1.03
Total		2.21±0.70	2.82±0.64	3.1±0.79	3.27±1.17

Gen: Gender; RSE: Real swimming experience; EE: Exergame experience; M: Male; F: Female; Y: Yes; N: No.

Discussion

The goal of this study was to compare enjoyment, usability, and gaming experience during a sport exergame in different performing groups and to check if active game play encourages players to participate in more PA and the real sport. Our results showed that psychological parameters were not different between performing groups. Moreover, participants did not change their intentions to participate in further PA but increased their real swimming intentions.

Enjoyment

Although Lai et al. (2012) showed that frequent exergame play may increase enjoyment, our results support the argument that gender (female), having swimming experience, and prior game experience may also contribute to enjoyment. While enjoyment may also predict future exergame play (Limperos & Schmierbach, 2016), our results suggest that it may not be a predictor of future PA and real swimming participation. Moreover, contrary to the previous research indicating that prior exergame experience can intrinsically be fulfilling and enjoyable (Depping et al., 2016; Huang & Gao, 2013; Sun, 2012), in our study enjoyment levels of experienced and novice players were not different. We also showed that female players enjoyed the game more than male counterparts, which was in contrast with the findings of Jenney et al. (2013). Presence was not a predictor of enjoyment in our study, which was in contrast with the findings of Limperos & Schmierbach (2016). Additionally, this study is one of the first studies to tie enjoyment and presence in sports exergames and future studies are needed to explore if PA during exergaming creates a stronger sense of presence and enjoyment compared to sedentary gaming. As enjoyment was reported as a crucial aspect of flow experience (Nakamura & Csikszentmihalyi, 2002) and with no association between these two in our study, it seems that challenge and deep concentration (Klasen et al., 2011) play even more important roles in characterizing flow. While it has been reported that exergames are less enjoyable than other types of video games (Lyons et al., 2011), it should be noted that removing or replacing traditional video games does not affect the enjoyment of PA (Abbott et al., 2014).

Usability and User Experience

Based on earlier research, this game meets the criteria of acquiring at least 70 points to be considered as "passed" for products evaluated by SUS (Bangor, Kortum, and Miller, 2009) and denoted high perceived usability from players. Since SUS and future real swimming intentions were moderately correlated, it is important for the game designers to include strategies in exergames to help induce usability. Our game setup and duration of game play were compatible with GEQ allowing players to immerse themselves in the game to answer the questions related to immersion component. Similar to the previous research (Depping et al., 2016), GEQ was not different among performing groups. The performance of the game itself might have contributed to keeping the game experience similar between performing groups.

Components of GEQ were also not different between different groups. Agarwal and Karahana (2000) argued that players' responses towards information technology (absorption) are influenced by perceived usefulness and perceived ease of use. As the movements of players were not completely transferred into the game (Soltani, Figueiredo, Fernandes, & Vilas-Boas, 2016), players might have rated absorption part of GEQ lower. It should also be noted that absorption is a general response to any form of information technology, whereas immersion is the actual experience of players during video gaming. Nogueira et al. (2016) mentioned that feedback functionality affects players' immersion; so as movement patterns of players were recognized similarly by the gaming platform, they might have immersed similarly. Although presence was not different between performing groups and as real swimmers mimicked the real-world swimming, they might have rated the presence component higher. Similar to the previous research, presence did not have any influence on future exercise intention which might have happened because of two possible reasons: i) either the technology did not make players think that it can substitute the real world activity; ii) or the exposure to the virtual world was not sufficient (Kim et al., 2014). While immersion is considered as the key part of good user experience, it might also be affected by other parameters such as task's challenge.

Future Intentions of PA and Real Swimming

Converting sedentary screen-time to activity is challenging and, as argued before, higher enjoyment and positive feelings of winning may contribute to the elevation of players' self-esteem, leading to more frequent participation in real sports (Adachi & Willoughby, 2015). However, contrary to previous research (Moller et al., 2014; Kim, 2007), our results show that exergames may not serve as a gateway to future PA participation. A possible explanation might be that future PA intentions of those who frequently exercise, may not be affected by playing exergames. Another explanation might be that those who do not exercise regularly, may think that the health benefits attained through exergaming are enough and there is no need for further PA participation (Van Nguyen et al., 2016). In addition to previous findings suggesting that novelty of exergames might influence future intention for exergaming (Garn et al., 2012), our results showed that it may not be motivating enough to encourage players to participate in real PA. In accordance with Baranowski et al. (2012), our results confirmed that prior exergame experience does not result in objectively measured increase in PA levels. Previous study suggested that female players are more likely to play exergames in the future (Limperos & Schmierbach, 2016) but similar to other studies (Xu et al., 2016; Adachi & Willoughby, 2013a; Adachi & Willoughby, 2013b), our data showed that gender in not a predicting factor for neither PA nor real swimming participation.

Similar to previous research, enjoyment of exergame was not an influencing factor for future sports participation (Wu & Theng, 2015), outlining the possibility of age and cultural influences on future PA intention. Although changes in PA intentions were not different, certain types of players (e.g. obese) enjoy exergaming more than other forms of PA (e.g. walking; Garn et al., 2012), and therefore, exergames might still provide engaging experience and to be used as a motivational tool in increasing PA levels. While previous research also suggests that parental support and presence of sports facilities are strongly correlated to moderate to vigorous PA and sedentary behaviors (Tandon et al., 2014), several other parameters might have contributed to why the presence of a sport exergame did not change PA intentions. Game mechanics (swimming in place) and lack of forces from water, might have induced an unrealistic feeling for the players. The pragmatic game play which happens even after short exposure to the game might have also contributed to non-different PA intentions. Lack of challenge and simplicity of current exergame might have also induced that the game is not a proper mean of PA. The medium effect size of swimming intention changes indicated that changes might be meaningful and support the idea that swimming exergame might encourage players to participate in real swimming following the game play. However, the magnitude of the main effect change in swimming intentions was not contingent on gender, real swimming, and exergame experience which means that either of groups did not change more than the other. While interest in PA and exergames might decrease through time, considering alternative challenges (e.g. harder levels and including various tasks) might encourage players to continue playing (Sun, 2012).

Limitations and future work

In this study we incorporated several psychological measurements to understand enjoyment and usability aspects of sport exergaming. However, due to the novelty of the game, players might have scored their enjoyment higher. While different games and platform alter enjoyment differently (Thin et al., 2013), it is important to measure these parameters on similar games across different platforms. Self Determination Theory (STD) in traditional exercise programs has shown that when basic needs are satisfied, enjoyment and exercise adherence increase (Vallerand, 2007). Previous research suggests that playing exergames fulfill those basic need (Lyons et al., 2014; Huang & Gao, 2013), and Jenney et al. (2013) showed that enjoyment of female participants increases following skills improvements. However, biomechanical studies have documented that after playing for some time, many players switch to pragmatic and with less effort game play (Soltani et al., 2016). Future studies are needed to confirm whether enjoyment and adherence will remain high and will not be affected by having a sense of mastery over the game.

Our sample consisted of college students that might enhance internal validity of the study but may limit generalizing the results. As SUS might also be influenced by age (Quiroga et al., 2009), it is important to consider participants with different age groups and different exercise backgrounds. Although players had the possibility to customize their avatar inside the game, which has been shown to affect exercise intention (Waddell et al., 2015), we used similar gaming profile for all players to avoid various exertion levels, resulting in biomechanical and physiological differences. While our game play duration was relatively long (around 30 minutes) and previous research suggests that flow can occur with a wide range of activity durations (Chen, 2007), comparisons of short-term and long-term gaming sessions are necessary to explore different reactions of players. Since many exergames consist of repetitive movements, boredom might also happen as players understand the mechanics of the games and therefore, longitudinal studies of enjoyment are necessary to adjust the games difficulties accordingly. While usability measurements may not be conductible in longitudinal studies, alternative methods such as ethnographical observations and qualitative users' feedback may be used. Future longitudinal studies should also explore if real sport intentions lead to future participation.

Conclusions

This was the first study to explore the changes in PA and real sport participation intentions which may provide information on perception of social environment created by exergames compared to other forms of PA. Based on the research and analysis of the data, this study suggests that swimming exergame might be used as a motivational tool to encourage players to participate in real swimming. It might be possible that novelty and entertainment elements of swimming exergame, played a role in influencing players' attitudes towards real swimming intention. As realistic movements are more likely to induce presence, improving the quality of platforms' movement detection might make the game play more natural and increase engagement in sports exergames. Balancing (manipulating game difficulty) mechanisms should also be adjusted carefully, so that novice players do not feel that things are happening automatically. Moreover, considering enjoyment as a complementary measurement provided insights on whether higher immersion was because of lack of enjoyment or being challenged by the difficulty of the task.

Conflicts of Interest

None declared.

Chapter 8 General Discussion

The concluding chapter discusses and maps the contribution of articles of this research project. We summarize the main findings and present them in an analytical framework that can be adopted for education and game design. This framework may assist PE and sports teachers, coaches, researchers, and game designers who want to design and employ sport exergames in their practice. As detailed discussions are presented in different papers of this thesis, this part will mostly focus on bridging between different domains and perspectives regarding the use of sport exergames for PE, sports, and health, and directions for future research.

The overall aim of this thesis was to evaluate the use of sport exergames, with a particular focus on evaluating their suitability for PE and sports. In order to meet the overall aim, different studies were conducted in this thesis that included a literature review on the application of sport exergames in PE, comparison of movement patterns during swimming exergames between different players, investigating the role of gaming velocity on muscle activation while exergaming, measuring EE and activity profile during sport exergames, and investigating how enjoyment, usability, and user experience affect future intentions of participating in PA and particularly in real swimming. Below, summaries of results of each study are presented.

Sport Exergames for PE and sports

The motivation for the review comes from the fact that PE-related aspects of serious games are not well explored. This is happening as these games may provide great and promising opportunities for practicing sports indoors. The goal of the review chapter was to provide a clear picture to physical educators who are willing to apply sport exergames in their practice. To understand the efficacy of using sport exergames in PE and sports domain, we reviewed the literature on motivation and literacy to play and exercise, learning and skill acquisition, and competition vs. cooperation while exergaming, and mentioned a practical application of these games in the real world scenario. This review led to the following observations and conclusions:

1- Exergames may provide motivation to play and exercise, but age and game design strategies should be tailored carefully.
2- Sport exergame may be used for basic skill transfer but may not be applicable for teaching sports.

To use sport exergames in PE, proper justification and design strategies are necessary. To make robust decisions about applying sport exergames in PE, identifying the gaps, problems, and limitations of these games using objective evaluation are necessary.

Kinematics of Swimming Exergame

To understand the movement patterns, participants played bouts of swimming exergame divided into normal and fast phases, and their movements were captured using a 3D motion analysis system. Our results showed that players had similar kinematic variables, and those who performed better inside of the game had fewer arm cycles and completed the event faster. Prior game experiences also resulted in fewer arm cycles. Players with real-swimming experience tend to keep their game play close to real swimming, but when they realized that their movements were not translated into the game, they also changed their movement patterns. Our data suggest that the Kinect sensor is not able to detect delicate movements of real swimming, and it may not be used for teaching and training real swimming. Moreover, although exergames require active participation, movement patterns may vary depending on games, systems, and players' experiences.

Muscle Activation During Swimming Exergame

Muscle activation can be used to confirm whether sport exergames increase PA levels and to make the gaming experience closer to the real sports. In this study, the effects of playing velocity on activation patterns of selected upper-limbs' muscles of male players were examined. Mean muscle activity differed between normal and fast swimming, but when normalized to playing velocity, these differences were selective. Based on the fast gaming activation patterns of LD and ES in the crawl, BB and ES in backstroke, LD during breaststroke, and BB, LD, and ES during butterfly, we can see that activations of these muscles were responsible for completing cycles (i.e. winning) and not swimming with correct technique. Moreover, when we divided different game phases into cycles and during the fast playing mode, we observed that players complete these phases faster. This might stress some of the muscles, and make them prone to injuries.

EE During Exergame

Proper EE measurement techniques are necessary to provide insights on using exergames as training tools for health and fitness. Creating activity profiles using time-motion analysis might also help developers to design more challenging video games. In this part, we measured aerobic and anaerobic energy systems contributions and activity profiles of players during swimming exergaming. Our results showed that lactate pathway accounted for 8.9±5.6% of total EE, and there were no physiological differences between performing groups, except higher HR values for players with real-swimming experience during front crawl. This shows that higher exertion levels are more likely at the beginning of the game play where players are not aware of gaming mechanisms yet. Based on video analysis, players were active 56.9±8.1% of the total game play, with an E:R of 1.3±0.3 which were lower in experienced players. Our data suggested that the gaming sensor does not allow considerable physiologic differences between different players. Other highlights of this part include:

1- Experienced exergame players are less active compared to novice players.

2- Participants with real-swimming experience do not have different levels of EE compared to non-swimmers.

3- Both aerobic and aerobic energy systems should be used in EE measurement of exergaming.

Usability, Game Experience, and Future Intentions of PA and Real Swimming

The goal of this study was to understand how enjoyment, game usability, and playability affects future intention of PA and real swimming participation. Questionnaires were administered, and the changes in intentions were monitored before and after the game play. Gender and real swimming and exergame experience did not have any effect on psychological measures and mean usability score was considered as good with high acceptability. Enjoyment was also not a predictor of future PA and real swimming participation. Other highlights of this part include:

1- Female players with real and exergame experience, enjoy swimming exergame
more.

2- Playing swimming exergame does not affect PA intentions.

3- Playing swimming exergame may increase real sport intentions.

Bridging between different studies

Kinematics and EMG

During the game play, participants with swimming exergame experience were less active and lowered the hands (upper body) less. This means that they tend not to swim close to real swimming and it seems that as soon as they figured out the game mechanisms (which usually happened after the first event), they changed their movement patterns to win the game. This was happening regardless of swimming event/muscle used. While there were also no differences in cycle time and kinematics between normal and fast swimming, normalized EMG was higher in fast swimming for almost all techniques. However, after normalizing the EMG signal to the gaming velocity, these differences were selective and mainly for those actions responsible for completing the cycle without considering the proper technique (i.e. winning the game). For example, during the front crawl, LD was responsible for flexing the arm downward, and ES was responsible for rotating the body to start a new cycle faster. Similar behavior was observed for other events, where starting a new cycle faster was more important to players than proper swimming.

Kinematics and EE

Players' similar movement patters between performing groups might have also translated into similar [La^-], EE, and RPE. However, HR was different between players with/out real swimming experience but only during the first event (crawl). Following the first event and when players understood the game mechanics, they changed their movement patterns. Additionally, novice players tend to be more active during the game play (as shown by TPT and EPT). As they did not know the game mechanics, they were completing all the movements included inside the game. For example, on the 50 m turn, where camera angle changes and shows the swimmer from another perspective, novice players tend to continue swimming, even if their movements were not necessary at that moment.

Kinematics and Psychology

It seems that although movements were not completely recognized by Kinect, players still enjoyed the game and rated the game highly. As SUS and future swimming intentions were moderately correlated, improving the game and platform movement detection mechanisms can also affect future real sport participation intentions. Improving game mechanics may also affect perceived usefulness and ease of use (which includes components of GEQ such as absorption and immersion). Although presence was not different between performing groups, the intentions of real swimmers to swim correctly (especially during the first event) might have made them rate the presence element higher.

EMG and EE

Many players changed their movement patterns and as a result, their muscle activation, after a short exposure to the game. This was also visible in non-different [La^-] and RPE among performing groups. That was why HR was higher in players with real swimming experience and only in the first event they swum.

EMG and Psychology

It seems that novelty of the game might have caused the game to obtain a high usability score regardless of players' performing levels and gender. As players' movement patterns were not captured by the Kinect and even after a short exposure to the game, they started to exert less just to win the game, it seems that they also did not perceive the game to be immersive, easily operable, or useful, and therefore, rated the components of GEQ equal to other players. Strategies to improve SUS might increase the intentions for related sport participation. Since enjoyment and future intentions of PA were not correlated, it seems that the game itself might not have any effect in encouraging players for more PA participation.

EE and Psychology

The fact that physiological parameters were not different between performing groups (except the HR of players with real swimming experience during the first event) might indicate that players did not find their correct movements useful for playing the game. Novice players also played the game for longer periods (i.e. higher TPT and EPT). This might have led the experiences players to rate components of GEQ lower. Lower TPT and EPT that could also justify why experienced players had lower immersion inside the game. Since performing groups had similar physiological parameters, their future PA participation might have remained similar as well.

Practical Implications

PA Promotion

Using exergames to promote PA seems promising, but several challenges must be addressed for successful implementation. Contrary to the promising short-term laboratory-based results of exergames showing that they increase EE, players may not continue the game play when they had a feeling of mastery over the game. While many games contain repetitive movements, challenge aspects of game play might be reduced causing players to lose interest over time (Graves, Ridgers, Atkinson, & Stratton, 2010; Maloney et al., 2008). This was also shown in previous studies, stating that long exposure to video games could decrease perceived situational interest and motivation to participate in exergame-based PA (Sun, 2012; Sun, 2013). Additionally, the costs of exergames are relatively higher compared to the level of game complexity they offer.

Another challenge is related to the game design itself. While some games have been shown to increase EE, some others might be less active. For example, Wii Boxing and Wii Fit have been shown to produce EE similar to self-paced walking (White et al., 2011), but others such as golf and bowling may only produce a small amount of EE above rest. Previous research has also shown that when only upper body movements are involved, they produce lower EE compared to when the whole body is involved (e.g. in dance video games; Ridley & Olds, 2001). In general, although they might have cognitive benefits, physical demands are not comparable to the real exercise, and it may not replace traditional sports and PA (Gao, 2013). Therefore, these games may not offer long-term maintenance of PA (Gao & Chen, 2014). This was also confirmed by our studies where players change their movement patterns and exertion levels even after a short exposure to the game. If exergames are intended to be used in PE and sports settings, one way to increase their varieties is to set them up in activity rotation stations. Other strategies could include several sport games into one package and to provide free updates to the players. Tan et al. (2016) also argue that by separating game play and exercise elements of exergames, higher immersion game play, and high-intensity exercising might be achieved.

Design

Many game developers consider players' behaviors as unsolvable problems. Based on our findings, it seems that players tend to change their movement patterns, or decrease their activity levels when they understood the game mechanics. This might be considered as cheating, and the theories behind the psychology of cheating in exergames might be under the same influence that encourages us to cheat in academics, business, and personal life. Cheating in exergames covers many different kinds of behaviors, and many modern games provide mechanisms (scores, ranking, losing inside-game rewards) that incentivize cheating. According to self-determination theory, people play games to feel competent at what they are doing (competence), to feel like they have meaningful choices when deciding how to do it (autonomy), and to feel connected and related to others in this process (relatedness). Competence needs are satisfied when our abilities are challenges without being too easy or demanding (Rigby & Ryan, 2011). Autonomy is a satisfaction of making meaningful choices while playing and players may have wanted to try new ways of playing the same routines that might have encouraged them to change their movement patterns. Relatedness deals with the need to feel a meaningful connection with other players. Many games provide multiplayer modes that require groups of players to complete. Missing the options players think they might have (reactance; Brehm, 1981) or to avoid losing the game, might have also contributed to players' changes in movement patterns. Short gaming sessions and presence of the researchers might have also prevented some of the players not to cheat or not to explore alternative movements. In general, technology and game design are crucial in increasing virtual presence inside game. While the game design might help in creating a mental model by providing similar real sport rules, technology (Kinect sensor) is still not advanced enough to trick our brain the same level as real swimming does.

Injury Prevention

Many psycho-biophysical methodologies that are described in this manuscript could also be used to identify the sources of fatigue to prolong the activity. For a safe and meaningful game experience, several injury prevention mechanisms may be utilized. Additionally, designing games according to correct posture and proper sequencing of movements (to avoid repetitive task on a certain joint, muscle, etc.) are often required. Biomechanical and ergonomic evaluation (consideration of game equipment and space) and proper use of the body to do the game tasks comfortably and safely are also important. Modifying the way that players play the games are often unavoidable, and one of the reasons why players are often trying to play the games with less effort might be to avoid pain and fatigue. Engaging video games may result in long playing time, and insufficient breaks and eagerness to proceed in the games might also be contributors. Therefore, creating players' activity profiles is crucial especially for those who are relying on video games to meet their training needs. Rest and proper sequencing between different levels are initial steps towards a safer game play. Designing games which use different muscle group is another factor to relieve stress on certain muscles. Stretching and postural exercises could also be used against pain. In addition, to maintain the presence (Yan et al., 2010), energy bars inside the game could also be effective in motivating players to complete the task and balance their exertion (Figure 8.1).

Figure 8.1. Energy bar (left) for balancing players' exertions.

Limitations

Although this work has several strengths, there are limitations that need to be acknowledged. To mitigate the limitations mentioned in Chapter 1, future studies might examine participants with/without sport background. More subjects might increase the statistical power and scientific robustness, and make the data more generalizable to a greater population. Due to higher body fat and limitations of EMG sensors, only male subjects were included in the EMG study. Future studies should include female players with other types of sensors.To avoid various workloads, we used similar gaming profiles for all players. While Pena, Khan, & Alexopoulos (2016) showed than players' avatar body sizes influence PA during exergames, future studies should consider effects of visual, auditory, and motion cues inside the games.

Chapter 9 Suggestions for Future Research

Our studies resulted in several recommendations for future research, which are necessary to gain insights on using sport exergames as training tools. The future work can take place in game development and exergame evaluation.

While the majority of studies show promising short-term results for increasing PA levels, our results showed that even after short exposures to sport exergames, participants change their movement patterns and reduce their exertion levels. Longer intervention periods and more participants might provide more realistic images of using exergames in PA and PE. We showed that playability and enjoyment are important in motivating players to participate in PA and the real sport. While questionnaires were typically used to measure these parameters after or before the game play, future studies could explore the motivational status of the players using, for example, video analysis (by measuring players' lengths of gaming time). Follow-up studies should analyze behavior over longer periods to assess changes in players' intentions over time.

Other ideas to be explored in the future include:

1- The relationship between RPE and $[La^-]$ in exergames.

2- The effects of warm-up on exergaming.

3- The relationship between the type of exergames (arcade, sport, dance, etc.) and enjoyment.

4- Using virtual swimming to decrease aqua-phobia.

5- Creation of game health index based on enjoyment, RPE, and EE.

6- The effects of gaming variety on playing continuity.

Chapter 10 Conclusions

In our research, we aimed to characterize a swimming exergame from different aspects. The presented studies have provided methods for designing better and more meaningful sport exergames. We measured the biomechanical parameters of the exergames, muscle activation of selected muscles, EE and activity profile during the game play, and usability, game experience, and future intention for participation in PA and real swimming, in players with different gender, game, and real swimming experiences. Following the results obtained in the studies presented in this thesis, it is pertinent to stress out the following conclusions:

1- The current thesis outlined that movement patterns during exergames are not affected by gender, exergame, and real swimming experience. This means that the gaming platform forces different players to play according to the limitations of the sensor. For example, players with real swimming experience do not swim according to real swimming patterns because the sensor fails to detect them. Therefore, future studies and designs should take the above elements into account, for designing more sensitive sensors.

2- Although exergames may offer promising short-term improvements in health and physical function, there are many differences and limitations associated with conducted studies. To successfully apply sport exergames, long-term studies and methodologies should be utilized.

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Appendix I

Exploring learning effects during virtual swimming using biomechanical analysis (a work in progress).

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Abstract

In this work-in-progress (WIP), kinematics of movement during playing virtual swimming exergame between novice and experienced players was analyzed to detect possible learning effects. Ten participants performed a 100-meter front crawl virtual swimming using Xbox and Kinect. A 12 camera Qualisys motion capture system tracked the position of 22 reflective markers simultaneously. Preliminary results indicate that novice players showed a pattern closer to real swimming, spending more time on the accuracy of movement, whereas the experienced players used an adaptive circular pattern to win the game.

Keywords: Exergame; Virtual Sport; Learning; Biomechanics

Introduction

Since 2000, new types of video game consoles (i.e. Microsoft Xbox and Kinect, Nintendo Wii or Sony Move) often tagged as Exergames have been introduced in which users have to interact physically to advance in the game. Claiming that Exergames can promote an active lifestyle, they don't actually increase levels of PA but rather the motivation to perform some basic repetitive movements (Peng et al., 2013). As one of the genres of popular games, virtual sports encourage participants to perform the activity as though they are playing the real sport. These systems use several methods to detect the movements of players. Adaptations to AVGs may happen after playing for some time. In fact, most of the users start playing technically rather than emotionally which means that they will learn how to play the game with less effort (Pasch et al., 2009). One of the causes is related to specifications of the platform used, which allows for the use of such strategies. For example, Nintendo Wii uses a sensor which detects the movement with an internal accelerometer. Although the optimum goal is to perform the complete movements in virtual sports, there is always the possibility of "cheating" due to the user being able to easily fool the accelerometer by using one's wrist to manipulate the controller (Lavac et al., 2009). This possibility is often discovered through experience or learning other players' styles of play.

On the other hand, as there is no exact force confronting players' actions, there are some concerns regarding efficacy and safety during the use of Exergames, especially when high exposure to the game is expected. Characterizing Exergames biomechanically allows designers to create more realistic games for a more meaningful experience; it will allow hardware developers to identify the limitations of their platforms in order to minimize the effects of learning; reduce musculoskeletal injuries (accidents due to limitations of players both in terms of space and muscle activity), and create additional resources (e.g. warm up and cool down periods). Therefore, the purpose of this work-in-progress is to compare spatiotemporal parameters between novice and experienced players to characterize possible learning occurring while playing virtual sports.

Methods

Ten healthy subjects (6 males and 4 females; Age: 22-31) played Michael Phelps: Push the Limit (505 Games, Milan, Italy) virtual swimming game using Xbox 360 and Kinect (Microsoft, Redmond, WA). Subjects were divided into two groups of "Bad Performers" if their ranking during the game was 1st to 4th and "Good Performers" if their position was 5th to 8th. All testing was conducted on the dominant arm. *Virtual Swimming:* Subjects had to stand in front of the Kinect sensor and had to bend forward and as soon as they saw the "Go!" command, they had to return to normal position with arms in front. After that, they had to swing their arms to move the avatar in the game (100-meter front crawl swimming). At the end of the event, they had to drop both hands and then raise one of them to finish the race. To prevent the player from swimming too fast or too slow, there is a spectrum on the screen with a blue zone in between which indicates if the speed is at the moderate level. At the middle of the second lap, there is a possibility to swim as fast as possible called "Push the Limit." We called it "fast" swimming.

Collection of Kinematics Data

Dominant arm's movements were recorded at 200 Hz with a 12-camera Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden). Before each experiment, the cameras were calibrated to the measurement volume. 22 spherical reflective markers were placed over the skin. The data collection was started when the subjects were placed at the "ready" position over a period of one minute. The data were collected in acquisition software (Qualisys Track Manager).

Swimming Technique and Definition of Cycles

The event was divided into four phases as suggested by Maglischo (1993). Based on the speed (Normal Vs. Fast), Good and Bad Performers were compared. The swimming cycle began with stretching the right arm forward which is considered as "Entry." As the so called propulsive phase of left arm finished, a phase called "Downsweep+Catch" starts. Some characteristics of this phase are different than in real swimming due to the position of the body. Following this phase, the hand moves in a circular sweep known as the "Insweep." Hand direction switches out, back, and up in a term called “Upsweep.” This phase finishes as the hand passes the thigh where its direction changes from back and up, to up and forward which is known as the “Recovery” phases.

Statistical Analysis

All data were statistically analyzed using SPSS version 20. An independent sample t-test was conducted to compare spatiotemporal parameters in two performance groups. Statistical significance was accepted at $p \leq 0.05$. One-way ANOVA was undertaken to evaluate stroke differences for movement quantity (path length, …) for the study sample as a whole. The Scheffé post-hoc multiple comparison test was used to identify individual stroke differences. Subsequently, for each stroke, for each outcome, a two-way repeated measure ANOVA was used to identify experience and trial differences.

Results

Total time to complete the event, numbers of cycles, start, average and max velocities, and angular distance covered during the event are presented in Table AI.1. A sample movement pattern created by a marker placed on the dominant hand in line with the index finger for both performance groups was shown in Figure AI.1. As shown especially in superior view, bad performers’ moving pattern is closer to real swimming following swimming phases in their performance while the good performers were creating a circular pattern. Time Motion Analysis and percentage of time dedicated to each phase is shown in Table AI.2. As shown in Table AI.1, Good performers completed the event in a significantly shorter time ($t(4.45)=-4.99$, $p = 0.01$). They also had lower numbers of cycles during both normal ($t(8)=-2.64$, $p = 0.03$) and fast swimming ($t(4.34)=-3.03$, $p = 0.03$). There were no differences in start velocity between the two groups ($t(8)=-0.19$, $p = 0.86$). Good performers had significantly lower velocity during the normal phase of swimming ($t(8)=-2.24$, $p = 0.05$). However, there were no significant differences in average velocity ($t(8)=-2.95$, $p = 0.78$) and maximum velocity during fast swimming phase ($t(8)=-1.34$, $p = 0.22$). Bad performers covered significantly more angular distance ($t(8)=-2.84$, $p = 0.02$).

Table AI.1. Spatiotemporal parameters of 100 m front crawl virtual swimming with two performing levels.

Parameters	Performance	N	Mean	Std. Deviation
Total time of event* (s)	Good	5	48.40	0.89
	Bad	5	57.00	3.74
Total numbers of cycles*:	Good	5	36.60	3.21
normal	Bad	5	46.40	7.63
Total numbers of cycles*:	Good	5	8.80	0.45
fast	Bad	5	11.80	2.17
Start velocity ($m.s^{-1}$)	Good	5	5.0640	1.64
	Bad	5	4.8760	1.53
Average velocity*:	Good	5	2.5160	0.52
normal ($m.s^{-1}$)	Bad	5	3.1720	0.39
Average velocity:	Good	5	3.9660	0.91
fast ($m.s^{-1}$)	Bad	5	4.1240	0.78
Max velocity: fast ($m.s^{-1}$)	Good	5	5.9100	1.10
	Bad	5	7.1480	1.74
Total distance covered* (m)	Good	5	115.00	24.32
	Bad	5	160.60	26.35

*: Significant differences were observed between the two performance groups.

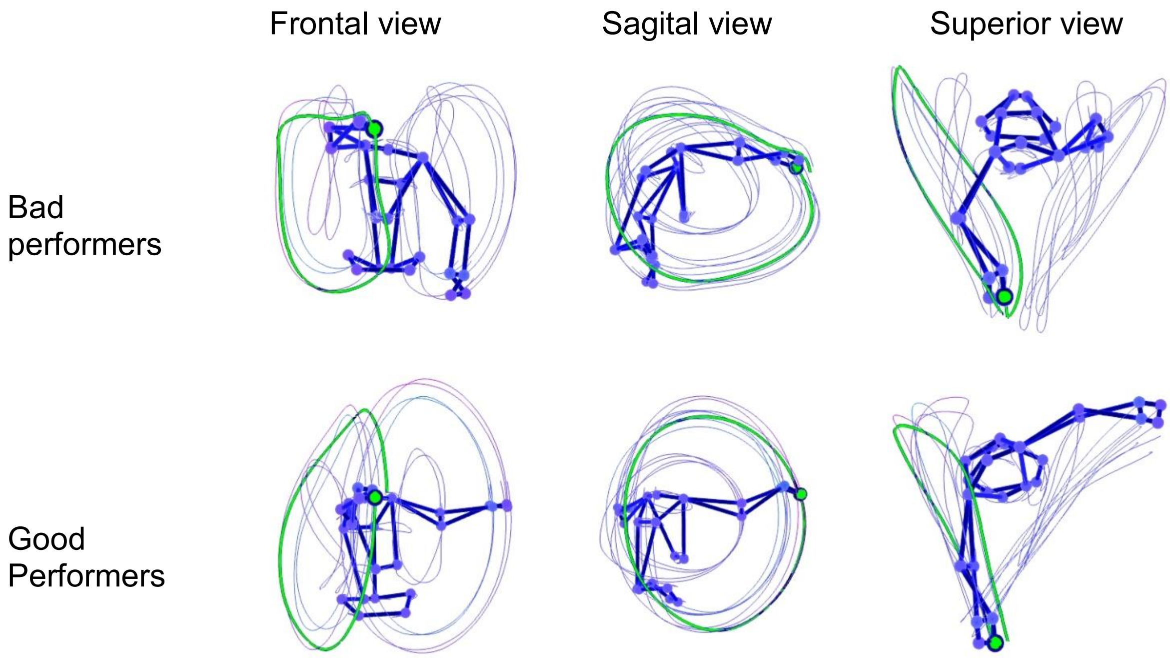

Figure AI.1. Sample hand pattern in one complete cycle in front crawl.

Table AI.2. Time Motion Analysis of different phases of virtual swimming between novice and experienced players.

Front crawl	Percentage of time in each phase: normal [fast swimming] Entry	Down+catch+ insweep	Upsweep	Recovery
Good performers	25±5 [25±1]	28±5 [25±3]	19±7 [20±2]	26±3 [27±2]
Bad performers	30±7 [30±6]	29±4 [27±4]	16±2 [19±3]	21±5 [22±5]

Numbers are expressed in Mean±SD.

Discussion

The purpose of this WIP was to detect the learning effects occurring during the playing of virtual sports using biomechanics. The preliminary results show that, in general, the movement pattern of bad performers was closer to real swimming. As a result of learning, good performers were focused more on completion of the circular movement. Bad performers wanted to adapt their movements to the spectrum and sometimes they swung their arms slower in order to decrease the speed of the avatar in the game. They dedicated more time to learning how to adapt to the game. Average velocity was lower in good performers because of the consistency of their movements. As good performers had lower numbers of cycles, angular distance covered was also lower. The good performers dedicated more time to the recovery phase as they were creating a circular pattern while bad performers spent more time to the down+catch+insweep phase which shows that they were following the real swimming pattern and therefore spent more time in this phase.

According to our observations, as bad performers entered the fast swimming phase (Push the Limit), they stopped following the real-swimming-movements. Good performers prioritized their movements to make more circular pathways. As good performers learned how to play the game, they perceived that real-swimming-movements were not necessary to play the game. Previously, virtual reality has been used to teach in several training programs (Snyder et al., 2011). As these gaming environments provide similar environments (Miles et al., 2012), and because of time constraints, virtual sport exergames might be a good alternative to be considered in tandem with traditional training methods. The biomechanical analysis used in the games may provide an image of how reliable these systems are in terms of teaching and structuring practice; especially when it comes to unsupervised long term usage.

Exergames may benefit players physiologically, but since the possibility of cheating exists due to the technical limitations of different platforms, developing a detailed characterization of these games may provide valuable information to be used in the feedback provided by these games. If we consider the process of learning during the use of exergames, good performers adapted their movement in order to win the game while bad performers were more focused on the accuracy of their movements. It seems that the Kinect sensor is not able to detect the delicate movements which may prove to be a good reason to switch from performing real movement to adaptive movements in exergames.

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Poster

EXPLORING LEARNING EFFECTS DURING VIRTUAL SWIMMING USING BIOMECHANICAL ANALYSIS

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ABSTRACT

In this work-in-progress (WIP), kinematics of movement during playing virtual swimming exergame between novice and experienced players was analyzed in order to detect possible learning effects. Ten participants performed a 100-meter front crawl virtual swimming using Xbox and Kinect. A 12 camera Qualisys motion capture system tracked the position of 22 reflective markers simultaneously. Preliminary results indicate that novice players showed a pattern closer to real swimming, spending more time on accuracy of movement, whereas the experienced players used an adaptive circular pattern in order to win the game.

INTRODUCTION

Since 2000, new types of video game consoles (i.e. Microsoft Xbox and Kinect, Nintendo Wii or Sony Move) often tagged as *Exergames* have been introduced in which users have to interact physically in order to advance in the game. Adaptations to active video games may happen after playing for some time. In fact, most of the users start playing technically rather than emotionally which means that they will learn how to play the game with less effort (Pasch et al., 2009).
On the other hand, as there is no exact force confronting players' actions, there are some concerns regarding efficacy and safety during the use of Exergames, especially when high exposure to the game is expected. Characterizing Exergames biomechanically allows designers to create more realistic games for a more meaningful experience; it will allow hardware developers to identify the limitations of their platforms in order to minimize the effects of learning; reduce musculoskeletal injuries (accidents due to limitations of players both in terms of space and muscle activity), and create additional resources (e.g. warm up and cool down periods).
Therefore the purpose of this work-in-progress is to compare spatiotemporal parameters between novice and experienced players to characterize possible learning occurring during playing virtual sports.

METHODS

- XBOX 360 + Kinect
  "Michael Phelps: Push the Limit" virtual swimming exergame
- 10 healthy subjects (6 male, 4 female; age: 22-31)
  Ranking during the event: GOOD = 1st - 4th; BAD = 5th - 8th
- 12-camera Qualisys motion capture system
  22 spherical reflective markers
- Dividing the event into different phases based on Maglischo (1993)
  Entry, Downsweep+Catch+Insweep, Upsweep, Recovery
- SPSS 20.
  Comparison of groups = Independent sample t-test ; $p \leq 0.05$

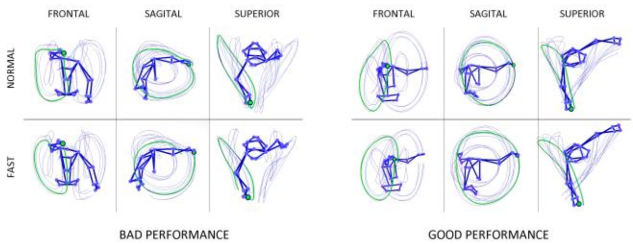
FRONT CRAWL	PERCENTAGE OF TIME IN EACH PHASE: NORMAL [FAST SWIMMING]			
	ENTRY	DOWN+CATCH+INSWEEP	UPSWEEP	RECOVERY
EXPERT	25±5 [25±1]	28±5 [25±3]	19±7 [20±2]	26±3 [27±2]
NOVICE	30±7 [30±6]	29±4 [27±4]	16±2 [19±3]	21±5 [22±5]

TIME MOTION ANALYSIS

RESULTS

	PERFORMANCE LEVEL	FRONT CRAWL
Number of players	GOOD	5
	BAD	5
Total time to complete the event* (s)	GOOD	48.40±0.89
	BAD	57.00±3.74
Total number of cycles: normal* [fast*]	GOOD	37 [8]
	BAD	46 [11]
Start velocity ($m.s^{-1}$)	GOOD	5.06±1.64
	BAD	4.87±1.53
Average velocity: normal* ($m.s^{-1}$)	GOOD	2.51±0.52
	BAD	3.17±0.39
Average velocity: fast* ($m.s^{-1}$)	GOOD	3.96±0.91
	BAD	4.12±0.78
Max velocity: push the limit phase ($m.s^{-1}$)	GOOD	5.91±1.10
	BAD	7.14±1.74
Angular distance covered* (m)	GOOD	115.00±24.32
	BAD	160.00±26.35

KINEMATICS



SAMPLE PATTERN OF MOVEMENT

DISCUSSION

Bad performers dedicated more time to learning how to adapt to the game. Average velocity was lower in good performers because of the consistency of their movements. As good performers had lower numbers of cycles, angular distance covered was also lower. The good performers dedicated more time to the recovery phase as they were creating a circular pattern while bad performers spent more time to the down+catch+insweep phase which shows that they were following the real swimming pattern and therefore spent more time in this phase. According to our observations, as bad performers entered the fast phase, they stopped following the real-swimming-movements. Good performers prioritized their movements to make more circular pathways. As good performers learned how to play the game, they perceived that real-swimming-movements were not necessary to play the game.
Exergames may benefit players physiologically, but since the possibility of cheating exists due to the technical limitations of different platforms, developing a detailed characterization of these games may provide valuable information to be used in the feedback provided by these games. If we consider the process of learning during the use of exergames, good performers adapted their movement in order to win the game while bad performers were more focused on the accuracy of their movements. It seems that the Kinect sensor is not able to detect the delicate movements which may prove to be a good reason to switch from performing real movement to adaptive movements in exergames.

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Figure AI.2. Conference poster.

Appendix II

Muscle activation during swimming exergame.

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Book of Proceedings of the XII International Symposium on Biomechanics and Medicine in Swimming, 5 pages

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Abstract
Swimming exergames may provide low-cost opportunities for teaching and practicing real swimming. The purpose of this study was to characterize the muscle activation during a swimming exergame. Ten healthy subjects played four swimming techniques using 'Michael Phelps: Push the Limit' exergame by standing in front of Xbox360 and Kinect. Muscle activations of BB, TB, LD, UT, and ES were recorded on the dominant upper limb using a wireless EMG Trigno system (Delsys Inc, USA) at the sampling rate of 2000 Hz, and was normalized to the maximal voluntary isometric contraction. EMG recordings were divided into a low intensity phase and the second phase of fast swimming. Both phases were evaluated in terms of EMG morphology (average peak value). Preliminary results show high contributions of UT. Particularly high activation values were obtained for the back crawl, where more expressive shoulder flexion is required. Lower contributions of other muscles might be related to lack of sufficient mechanical resistance. Prevalence of the activity of the Tri relatively to the Bi was also observed, as expected, considering the final acceleration of the lower part of the arm in all swimming techniques. Due to great activity of UT, proper warm up and the use of strategies to transfer the muscle activity are advisable. More results of this ongoing project will be available in the future.
Keywords: biomechanics, muscle activation, virtual swimming, surface electromyography

Introduction

Video game playing is increasing among youth (Lenhart et al., 2008) with the gaming experience being changed significantly in the last years. As they are part of screen-based activities which account for players' sedentary time, high exposures to video games have raised physiological and psychological concerns (Roberts et al., 2004). This has led to design a new type of video game (tagged as AVGs or Exergames) in which the players can interact with the game physically and more naturally, hypothetically increasing PA levels regarding other screen-based activities. These gaming platforms use accelerometers, infra-red depth sensors, and cameras to detect player's movements to simulate on-screen game play. Using Kinect (see Leyvand et al. (2011) for details), players can interact with the game without holding anything, as it can detect full body joint segment (Zhang, 2012).

According to the ESA (2011), sports video games are the second "action" genre in terms of popularity. Hayes and Silberman (2007) suggested that exergames should be of interest in PE to increase motivation and facilitate motor skill learning. However, a detailed evaluation is needed to "prove" the benefits of sport exergames. If it shows similar movement patterns as real sports, they can potentially be a low-cost and effective tool in teaching and training sports. Understanding muscular activation while playing exergames allows safe playing for both players and their peers. As most of the exergames consist of repetitive tasks, excessive playing of exergames have led to injuries, and medical doctors introduced Wii shoulder (Cowley & Minnaar, 2008), Wiiitis (Bonis, 2007; Nett et al., 2008) and X-boxitis conditions after playing too much AVGs. Risks caused by the game may be controlled by monitoring muscle activation during playing, which is especially important when the games are so engaging that the players would not be completely aware of their body and the time they spend on playing. Moreover, as exergames might be a good tool for unsupervised and self-directed rehabilitation, understanding muscular involvement is also necessary for considering prescription and for effective and secure training sessions (Tanaka et al., 2012).

The design of games and different controllers may affect posture and muscle loading (Lui et al., 2011). As enjoyment and other factors may contribute to high exposure of people to these games, a detailed biomechanical analysis during game design may prevent potential musculoskeletal symptoms. To make video games more realistic, "Naïve Physics" which is the human perception of knowledge about the physical world, was introduced by Jacob et al. (2007). Applying the same physical principles of real sports while designing exergames may allow a more meaningful game play. This is important when participating in real sports happens before playing the exergame (Mueller et al., 2009). Characterizing exergames is helpful in designing harder levels while preventing a sudden occurrence of fatigue. It seems that sport exergames have the potential to be used within the PE and sports settings. However, this needs to be supported by empirical evidence. To date, very few studies analyzed and compared muscular activity in exergames. Thus, to build a muscular activity profile for exergames, the purpose of this study was to provide the level of muscle activation in a swimming exergame.

Methods

Ten healthy male subjects who had no physical injuries (age 24.1±3.3 yr; weight 71.7±6.1 Kg; height 175.1±7.2 cm) played bouts of a swimming exergame. The pilot study was conducted at the University of Porto Biomechanics Laboratory (LABIOMEP). Participants were recruited online, face-to-face and through flyers. Informed consent forms were signed by participants prior to testing and procedures were approved by the local ethics committee. Anthropometric measures were taken, and the participants were familiarized with the equipment and the procedure. As part of the game, they watched a brief instructional video in which playing with the game was demonstrated.

EMG sensors were placed on the dominant upper limb/side of players (Figure AII.1 B). The muscles of interest for this study were the BB, TB, LD, UT, and ES, which are frequently used in swimming (Mcleod, 2010). ES was considered as players had to lean forward in the beginning and at the end of the game play. Electrodes were placed according to SENIAM recommendations

(Freriks et al. 1999). Skin Preparation involved cleaning, dry shaving, rubbing with alcohol-soaked pads and then allowing alcohol to vaporize. Muscle activation was recorded using a Trigno Wireless EMG System (Delsys Inc., USA) at a sampling rate of 2000 Hz, for both MVIC and Exergame trials.

The Biodex System 4 (Biodex Medical Systems, Shirley, NY) was used to obtain MVICs and was calibrated before each use according to the manufacturer´s instructions. Three MVIC attempts for each muscle were obtained, Each one lasted 10 s (2 seconds rest in the beginning, 5 seconds of muscle contraction and 3 more seconds to reduce gradually ending with a new isoelectric line) with one minute rest between attempts. The MVIC values were chosen from the highest value of the three attempts and used to normalize the trial data. Verbal encouragement was provided throughout the MVIC attempts. The positioning of Biodex was performed according to Gennisson et al. (2005) for Bi and Lategan & Kruger (2005) for Tri. For UT and LD, MVICs were performed according to Hong et al. (2012), and for ES, we followed Moreau et al. (2001).

The exercise task was a swimming exergame designed for Xbox gaming platform. The software used was “Michael Phelps: Push the Limit” (505 Games, Milan, Italy), a game that offers different swimming techniques and uses Kinect (Figure AII.1 A), which connects to the Xbox via a USB cable, allowing users to interact physically with the game. A promotional video is available here: http://goo.gl/zPvHZL. Four swimming techniques mimicking the four competitive swimming techniques were played randomly during this study. Each event consisted of 100-meters of virtual swimming. Subjects had to stand in front of the Kinect sensor, bent forward and, as soon as they saw the “Go!” command, they had to return to normal playing position: slightly bent forward, with shoulder partially flexed, and upper limbs in front of the body (shoulder extension) (Figure AII.1 C). After that, they had to swing their arms according to the technique to move the avatar in the game (100 meters front crawl swimming). At the end of the event, they had to drop both hands and then raise one of them to finish the race (corresponding to virtually touching the end of the lane). To prevent the player from swimming too fast or too slow, there is a spectrum on the screen with a blue zone in the middle which indicates if the cycle frequency is at the moderate level. At the middle of the second lap, there is a possibility to swim as fast as possible called “Push the Limit.” If players swim with a constant speed, they could reserve energy on a so called energy bar to exert more in the push the limit phase.

Figure AII.1. Game screenshot (A), the positioning of sensors (B) and participants as they play (C).

EMG data processing was performed using EMG Works Analysis 4.0 (Delsys Inc, USA), and it included signal filtering between 20-450 Hz, full-wave rectification and Root Mean Square (RMS) envelope calculation using a 150 ms window. This process was performed for both the MVIC and the trial data. A paired t-test was run on each technique to determine whether there is a statistically significant mean difference between the five muscles in normal and fast mode ($p < 0.05$).

Results

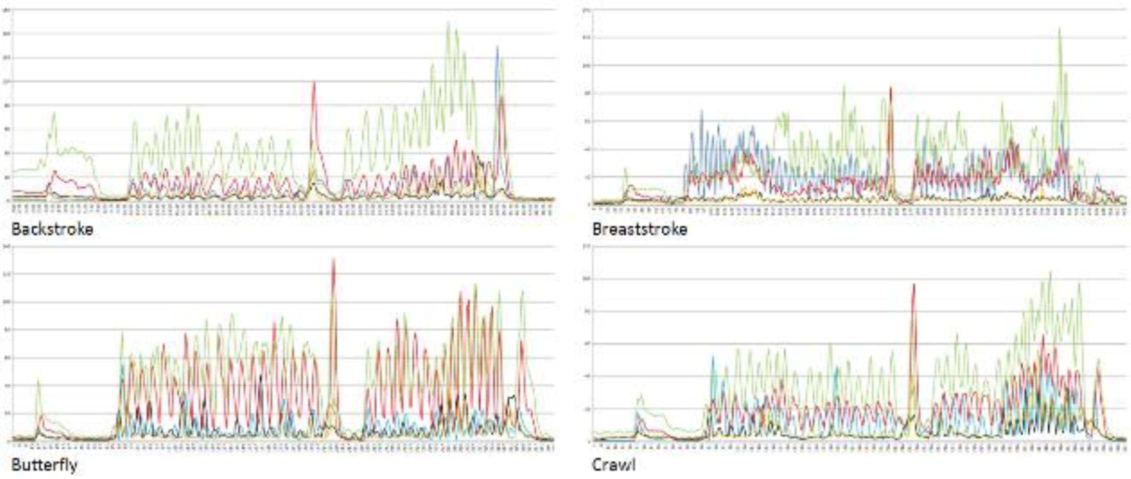
Table AII.1 presents EMG RMS mean±SD data expressed as a percentage of MVIC, obtained during “normal” and “fast” swimming from the selected muscles. The paired t-test showed significant change between normal and fast swimming in breaststroke ($t(4) = -4.27$, $p = 0.01$), butterfly ($t(4) = -3.49$, $p = 0.02$), and crawl ($t(4) = -3.80$, $p = 0.01$). There was not a significant change in back crawl between the muscles from normal to fast swimming phases ($t(4) = -2.67$, $p = 0.06$).

Table AII.1. Muscle activation levels (normalized to %MVIC) during swimming exergame for selected muscles in two virtual swimming phases.

		Bi	Tri	LD	UT	ES
Back Crawl	Nr	4.9±2.4	17.0±16.2	15.4±10.4	47.0±15.5	6.8±4.1
	Fs	8.2±5.0	23.7±22.1	21.7±18.1	69.3±18.6	13.4±7.3
Breaststroke*	Nr	10.0±5.5	19.0±18.2	11.1±6.7	29.0±19.3	5.0±2.6
	Fs	18.3±7.2	28.8±31.7	20.6±12.4	46.1±40.8	8.1±4.5
Butterfly*	Nr	5.6±2.0	23.4±21.3	24.4±32.7	43.8±19.0	5.5±2.4
	Fs	9.7±3.9	33.1±26.2	50.8±66.8	65.4±34.4	15.8±10.2
Crawl*	Nr	8.2±3.1	16.2±15.6	11.8±7.6	39.7±22.5	7.1±4.1
	Fs	15.2±4.8	23.0±24.6	22.9±14.9	63.7±31.5	18.1±13.0

*: significant changes were observed between normal and fast swimming in muscle groups; Nr = Normal; Fs = Fast.

Figure AII.2 presents a visual time sequencing of muscle activation.



_BB; _TB; _LD; _UT; _ES; High resolution image is available at http://goo.gl/FYaCPh.

Figure AII.2. Time sequencing of muscle activation.

Discussion

Preliminary results show high contributions of UT in all techniques. This is probably because players always have to hold their upper limbs up/front during playing (shoulder flexed). Particularly high activation values were obtained for the back crawl, where more expressive shoulder flexion/rotation is required. In addition, players tended to face the screen and avoided rotation their bodies, which may justify why there were not any significant changes between normal and fast swimming as players had to exert a lot during both phases. The activation pattern for Bi and Tri were similar in the crawl, back crawl and butterfly. After the elbow reaches a point of maximal flexion (which occurs when the arms are down), Tri assists the arms to be lifted (starting push phase) progressing into an extended position. Interesting to note is the persistent pattern of co-contraction of this pare of antagonists, probably for elbow stabilization. Shortly after recruitment of the Tri, UT would be activated again holding the arms all the way through the push and recovery phase.

In crawl, the activation of LD is in accordance with Bi. As the arms are down, the activation of LD finishes leading to recruitment of Tri. The activation pattern of LD and ES fades away as players switch from playing emotionally (really completing the cycles) to technically (in a way that much of the work is being done by gravity). As they start the fast swimming phase, these patterns become visible again showing that those muscles are helping to extend the upper limbs again to complete the cycles. As activation of ES serves a key in the coordination of the body roll, lack of activation of this muscle shows that players tended to face the television and do the movement without rotating the body (the same situation occurs in the butterfly). This happens as the players wanted to synchronize their cycle frequency with the visual feedback on the screen. In the fast phase of swimming, where no visual feedback was given, players tended to rotate their body (activation of ES) along with other muscles.

In breaststroke, the activity pattern of Tri and UT were similar. Tri extends the arms completely to the front and meanwhile UT is bearing the weight of upper limbs. UT remains active even in the so called recovery phase as it is still holding the upper limbs. Due to great activity of UT, proper warm up and the use of strategies to transfer the muscle activity is advisable. Lower contributions of other muscles are most probably related to lack of sufficient mechanical resistance of air. This suggests that increasing mechanical resistance to arms' movements may be a solution to implement the game playing conditions. Prevalence of the activity of the Tri relatively to the Bi was observed, as expected considering the final acceleration of the lower arm in all swimming techniques.

The empirical evidence that supports the effectiveness of sport exergames systems in teaching and training real sports is limited, since no study characterized sport exergames to provide an insight on how real they are when played. This study aims to create a muscle activation profile during playing a sport exergame. Although this swimming exergame is mostly different than real swimming (e.g. body position and forces applied to the body), swimming technique needs to be the same for a meaningful experience. More results of this ongoing project will be available in the future.

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Poster

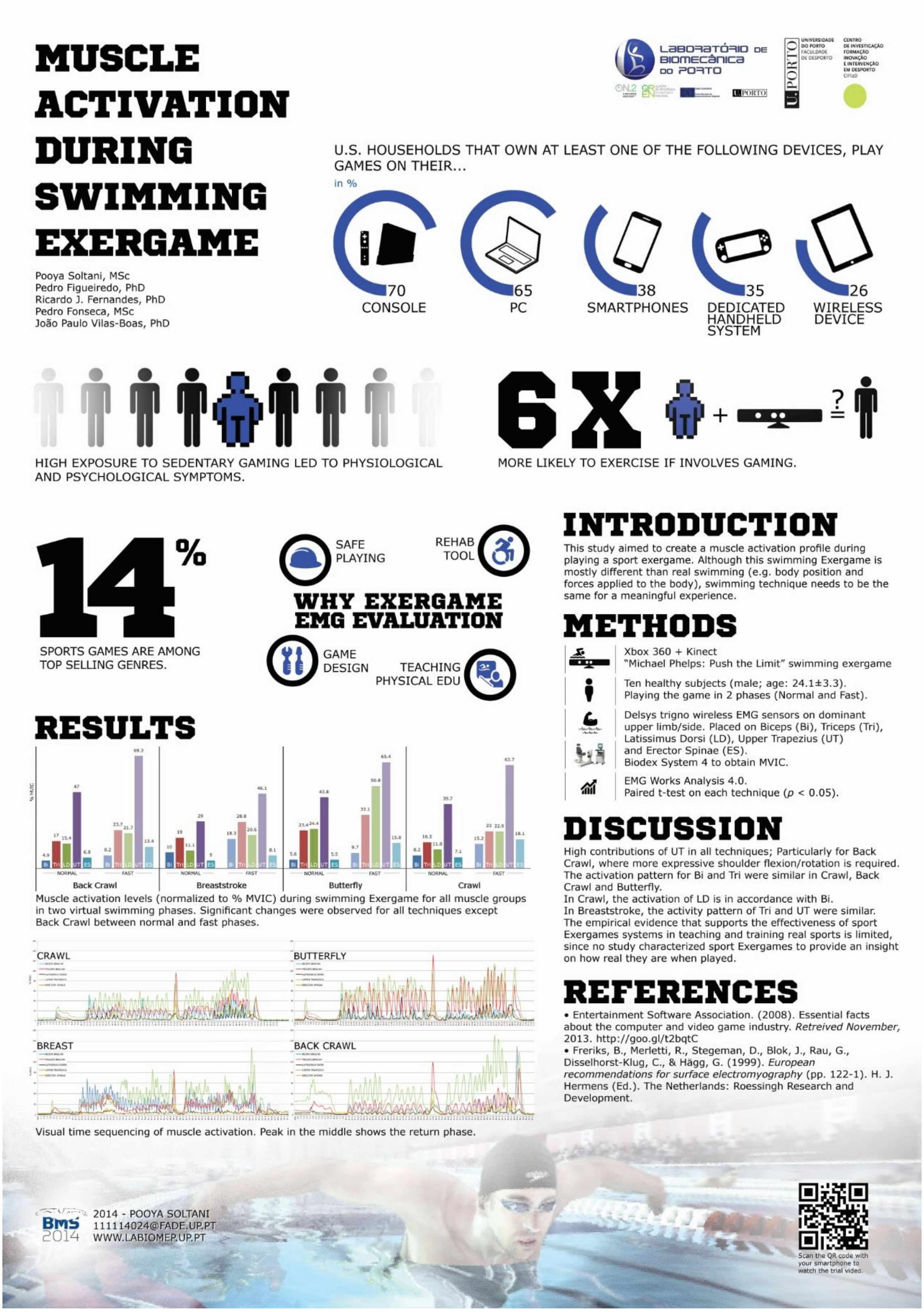

Figure AII.3. Conference poster.

Appendix III

Exergame playing in novice and experienced children: A pilot study.

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Abstract

Objective: Exergames may decrease sedentary video game playing in children. By evaluating the experiences of those playing these video games, we may learn valuable insights as to the potential uses of this new generation of video games for encouraging PA. The purpose of this study was to compare total and effective playing time between novice and experienced exergame players. Methods: 10 healthy children aged 7-10 yrs played “Michael Phelps: Push the Limit” swimming Exergame using Xbox and Kinect. The game was divided into different phases tagging as active or inactive. Total Playing Time (TPT), Effective Playing Time (EPT), Resting Time (RT) and Effort to Rest Ratio (E:R) were measured based on video analysis. Exergame experience was based on self-report. Results: Data are presented as [Novice vs. Experienced] respectively. Mean TPT (1072 vs. 1034s), RT (580 vs. 503s), EPT (427 vs. 509s) and E:R (0.79 vs. 1.04) were not significantly different between groups based on independent t-test ($t(9) = -0.374$, $p = 0.717$; $t(9) = -0.742$, $p = 0.477$; $t(9) = 1.204$, $p = 0.259$; $t(9) = 1.238$, $p = 0.247$ respectively for TPT, RT, EPT and E:R) ($p \leq 0.05$). Conclusion: Players with lower experience spent more time navigating between the menus before really engaging in the activity, which increased their resting period.

Acknowledgment: Authors would like to thank Ana Inês Alves and Andreia Flores for their help.

Poster

EXERGAME PLAYING IN NOVICE AND EXPERIENCED CHILDREN

Pooya Soltani, MSc
Pedro Figueiredo, PhD
Amin Mehrabi, MSc
João Paulo Vilas-Boas, PhD

METHODS

Xbox 360 + Kinect
"Michael Phelps: Push the Limit" swimming Exergame.

Ten healthy subjects (age: 7-10 yrs)

Camera, Magix Video Edit Pro, Heart rate monitor
Dividing different phases of the game into Active and Rest (based on time motion analysis).

IBM SPSS Statistics 20.
Independent t-test ($p < 0.05$).

Total Playing Time: Defined as duration of Exergame playing as a whole.
Effective Playing Time: Defined as the time crucial to operate the game.
Resting Time: Defined as the time when the game is being loaded or the players do not engage in the activity.

INTRODUCTION

Active video games might be promising ways in increasing physical activity in children and adults through increasing energy expenditure (EE). Several studies indicated that playing such games involves significantly greater EE than playing sedentary computer games.
This study aims to provide an analysis of work-rate profile of an Exergame during normal gameplay.

DISCUSSION

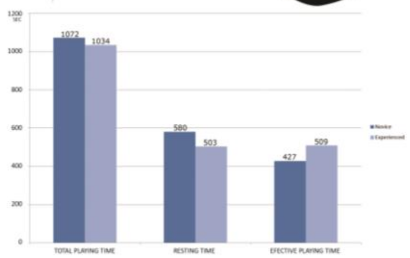
Players with lower experience spent more time navigating between the menus before really engaging in the activity, which increased their resting period.
Novice players spent more time between different strokes causing the heart rate to decrease more at the beginning of the new strokes.
Experienced players understood the mechanisms of the game and did not participate in the whole scenario of the game leading to increased rest time.
Styles of play can change effort:rate ratio in Exergame players and therefore, game designer could improve their game design by vivifying the "dead" space inside each game. Smart usage of music and encouraging graphics are recommended.

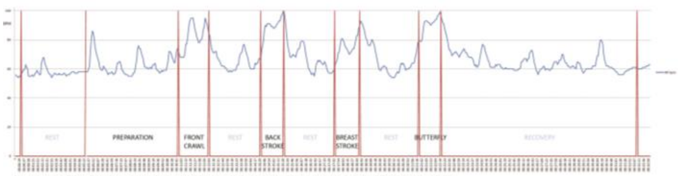
Scan the QR code with your smartphone to watch the video playlist.

RESULTS

Phase	Role in game	Time (s)
Stand in front of sensor	Rest	0
Shake to Play	EPT	16.4
Select profile	EPT	23.5
Select profile again	EPT	5.1
Being in the center	EPT	6
Select Quick Play	EPT	14
Select Player	EPT	5.6
Select Stroke	EPT	0
Press Start	EPT	51.9
Presentation and teaching	Rest	95.4
Loading	Rest	29.1
Entering pool and Graphics	Rest	20
Hype for the crowd	EPT	14.1
On your marks START	EPT	6.2
Swim	EPT	12
Half way Swim	EPT	20
Return (continuing the hand movement)	EPT	3.5
Push the Limit	EPT	9
End	EPT	15.3
Total Playing Time (EPT)		350
Effective Playing Time		202.6
Rest		144.5
Effort to Rest Ratio		1.40

TIME-MOTION ANALYSIS (CRAWL)





SAMPLE HEART RATE DURING PLAYING SWIMMING EXERGAME

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Figure AIII.1. Conference poster.

Appendix IV Questionnaires and Forms

We used a custom-made online system for conducting questionnaires. Upon arrival, subjects were asked to create a profile on our system. Following that, Appendices IV.1 and IV.3 were filled, and they got acquainted with the procedures through IV.4. Then they were asked to electronically sign informed consent (IV.5). A confirmation code was sent to their emails, and upon confirmation, a copy of signed consent form was sent to the researcher and participant. For our study with children, we asked their parents or legal guardians to sign the consent form (IV.6) and fill the IV.7 electronically or on paper. We also asked the participating children to sign the informed consent (IV.8).

To minimize the effects of tests on one another (ACSM, 2005; Heyward, 1998), we followed the following order:

1- Resting heart rate
2- Body composition
3- Kinematic evaluation
4- Muscular evaluation
5- Cardiorespiratory evaluation

Following the game play, participants filled IV.9, IV.10, and IV.11. After participating in the study, a debriefing letter (IV.17) was sent to the participants via email.

References

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Appendix IV.1. Participant Pretest Screening Questionnaire

Tester:	Date:	Testing location:
Temperature:	Humidity:	Testing time:
Name of participant:		Date of birth:

Age:

Gender: ○ Male ○ Female ○ Other

Education level: ○ Some high school ○ Some university ○ Graduate studies

ethnical background (check as many as needed):

○ Caucasian ○ Black/African-American ○ Hispanic ○ Asian Other:

Height (cm):

Mass (kg):

Home telephone:

Mobile phone:

Home address:

Email address:

Diet

How would you rate your diet over the last 2 days?

○ Poor ○ OK ○ Good ○ Excellent

How many hours ago did you eat your last meal?

Record foods eaten over the last 24 h:

Meal	Food including drinks	Portion size (cups, grams)
Breakfast		
Snacks		
Lunch		
Snacks		
Dinner		

Environment

Have you been training in hot conditions over the last 2 weeks? Yes ○ No ○

If yes, provide details:

Have you been training or sleeping at altitude in the last 2 weeks? Yes ○ No ○

If yes, provide details:

Illness

Are you currently suffering from any type of illness? Yes ○ No ○

If yes, provide details:

Did you have any type of health problem/illness in the last 2 weeks?

Yes ○ No ○

If yes, provide details:

Musculoskeletal Screening

Do you currently have any injuries? Yes ○ No ○

If yes, provide details (Date, Injury):

Have you had any injuries in the last 2 weeks? Yes ○ No ○

If yes, provide details:

Health
Assess your health needs by marking all true statements.
History
You have had:
○ A heart attack
○ Heart surgery
○ Cardiac catheterization
○ Coronary angioplasty (PTCA)
○ Pacemaker / implantable cardiac defibrillator / rhythm disturbance
○ Heart valve disease
○ Heart failure
○ Heart transplantation
○ Congenital heart disease
Symptoms
○ You experience chest discomfort with exertion
○ You experience unreasonable breathlessness
○ You experience dizziness, fainting, or blackouts
○ You take heart medications
Other Health Issues
○ You have diabetes
○ You have asthma or other lung disease
○ You have burning or cramping sensations in your lower legs when walking short distances
○ You have musculoskeletal problems that limit your physical activity
○ You have concerns about the safety of exercise
○ You take prescription medications
○ You are pregnant
If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a medically qualified staff.
Cardiovascular Risk Factors
○ You are a man older than 45 years
○ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal
○ You smoke, or quit smoking within the previous 6 months
○ Your blood pressure is >140/90 mmHg
○ You do not know your blood pressure
○ You take blood pressure medication
○ Your blood cholesterol level is >200 $mg \cdot dL^{-1}$
○ You do not know your cholesterol level
○ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)

○ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week)

○ You are >20 pounds overweight

If you marked two or more of the statements in this section, you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a professionally qualified exercise staff [*] to guide your exercise program.

○ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

Medications and Supplements

Are you currently taking any medication? Yes ○ No ○

If yes, provide details:

Have you taken any medication over the last 2 weeks? Yes ○ No ○

If yes, provide details:

Have you taken any supplements over the last 2 weeks? Yes ○ No ○

If yes, provide details:

Motivation

Evaluate your motivation for testing today. ○ Poor ○ OK ○ Good ○ Excellent

Training

	Not at all				Extremely		
	1	2	3	4	5	6	7
How fatigued are you today?	○	○	○	○	○	○	○

How many hours ago did you last exercise?

Describe your last three training sessions:

Time	Training session	Difficulty (easy, moderate, hard)
Today		
Yesterday		
2 days ago		

	Never				Frequently		
	1	2	3	4	5	6	7
Are you physically active? (most days of the week)	○	○	○	○	○	○	○
How often do you perform weight-based exercise?	○	○	○	○	○	○	○
How often do you perform cardiovascular exercise?	○	○	○	○	○	○	○

Are you a swimmer? (You know at least two swimming strokes) ○ Yes ○ No

[*] Professionally qualified exercise staff refers to appropriately trained individuals who possess academic training, practical and clinical knowledge, skills, and abilities commensurate with the credentials defined in ACSM 2010.

	Not likely at all 1	2	3	4	5	6	Very likely 7
If I had a chance, I would participate in physical activity later today.	○	○	○	○	○	○	○
If I had a chance to participate in physical activity, I would choose swimming.	○	○	○	○	○	○	○

Travel

Have you had to travel over the last 7 days? Yes ○ No ○
If yes, provide details:

Miscellaneous

Please provide any additional information that you believe may influence your testing results:

References

AIS - Australian Institute of Sport. (2013). Physiological tests for elite athletes, 2nd ed., Champaign, IL: Human Kinetics.

Appendix IV.2. Pretest Checklist for Testing in the Laboratory

Testing Environment

○ The risk minimization process for the test protocols is completed.

○ The laboratory is clean and free of hazards. The testing area has been defined and cordoned off if required.

○ The equipment to be used is calibrated and operating correctly.

○ All equipment for the testing session are prepared (i.e., make up mouthpieces, warm-up metabolic cart, stock and prepare blood trolley for use).

○ Laboratory conditions are appropriate for testing. The temperature is maintained between 18 and 23 °C, relative humidity is less than 70%, and environmental conditions have been noted on the testing recording sheet.

○ The time of day is recorded on the testing recording sheet.

○ The use of air conditioning system during the testing session is noted on the testing recording sheet.

○ Testers and athletes have appropriate access to first aid facilities and medical assistance.

Procedural Considerations

○ All pretest conditions, as specified in the protocol, have been implemented.

○ The test order was established (as per the test protocol) if multiple tests are being conducted.

○ A copy of the test protocol is printed and readily available for staff conducting the testing.

○ Testing recording forms, the rating of perceived exertion (RPE) chart, and all other relevant documentation and forms are available.

○ Staff members are appropriately trained and competent to conduct the tests.

Subject Preparation

○ Subjects have been medically screened prior to testing.

○ Subjects have signed the informed consent form.

○ Subjects have completed the pretest questionnaire.

○ Subjects are in good health and injury free.

○ Subjects are dressed appropriately (light and nonrestrictive clothing).

○ Subjects are familiar with the testing protocols.

○ All subjects are encouraged to give their best efforts.

References

AIS - Australian Institute of Sport. (2013). Physiological tests for elite athletes, 2nd ed., Champaign, IL: Human Kinetics.

Appendix IV.3. Video Game History Questionnaire

1- Have you ever played video games or computer games? ○ Yes ○ No
2- Have you ever played with Active Video Games? (Xbox and Kinect, Wii, Sony, or Dance Dance Revolution). ○ Yes ○ No
3- Would you consider yourself a "gamer?" ○ Yes ○ No
4- Do you currently play video or computer games? ○ Yes ○ No
5- What game system(s) do you use (choose all that apply):
○ Nintendo Wii ○ PlayStation ○ Xbox ○ Gameboy ○ Nintendo 3D or 3DS
○ PSP ○ iPhone/iPad ○ Computer Other (please specify):
6- How long have you owned each gaming system?

Nintendo Wii	PlayStation	Xbox	Gameboy Nintendo
3D or 3DS	PSP	iPhone/IPad	
Computer	Other (please specify):		

6- How many games do you currently own for each gaming system?

Nintendo Wii	PlayStation	Xbox	Gameboy Nintendo
3D or 3DS	PSP	iPhone/IPad	
Computer	Other (please specify):		

	Not at all 1	2	3	4	5	6	Extremely 7
7- How familiar are you with Xbox and Kinect?	○	○	○	○	○	○	○

8- Have you played "Michael Phelps: Push the Limits" before? ○ Yes ○ No
9- How many hours per day, on average, do you play video games?
Weekdays
Weekends
10- How many hours per day, on average, do you play computer games?
Weekdays
Weekends
11- How often do you play each of the following types of video/computer games?

Type	Days/week	Hours/day
Action/adventure		
Arcade-like with violent themes (such as Asteroids)		
Arcade-like without violence (such as Tetris)		
Human violence		
Non-human violence (such as Legend of Zelda)		
Role playing		
Sporting		
Strategy		

12- How often do you play each of the following types of video/computer games…
With a partner in person

Type	Days/week	Hours/day
Action/adventure		
Arcade-like with violent themes (such as Asteroids)		
Arcade-like without violence (such as Tetris)		
Human violence		

Non-human violence (such as Legend of Zelda)
Role playing
Sporting
Strategy
With a partner online

Type	Days/week	Hours/day
Action/adventure		
Arcade-like with violent themes (such as Asteroids)		
Arcade-like without violence (such as Tetris)		
Human violence		
Non-human violence (such as Legend of Zelda)		
Role playing		
Sporting		
Strategy		

13- What are the top 5 games that you currently play?
Game 1
Game 2
Game 3
Game 4
Game 5
14- What category of video games (see #11) would you place your responses to #13?
Game 1
Game 2
Game 3
Game 4
Game 5
15- How often do you play the games from #13?

Type	Days/week	Hours/day
Game 1		
Game 2		
Game 3		
Game 4		
Game 5		

16- Do you live with someone who plays video or computer games?
○ Yes ○ No
17- How often, on average, do you watch someone play video or computer games?
Days per week
Hours per day: weekday
Hours per day: weekend
18- What is your handedness? ○ Right handed ○ Left handed ○ Ambidextrous

Appendix IV.4. Explanation of Psycho-Biophysical and Anthropometric Assessment Procedures

Information for participants

Consent and pre-participation questionnaires

Welcome to the virtual swimming study. Before we begin, please read over the consent form. If you have any questions, please do not hesitate to ask. After reading the form, if you wish to continue participating, sign the form electronically (a confirmation email will be sent to you and the researchers).

<wait until participant is finished with the form>

Here are the pre-participation surveys. Please fill them out and let me know when you are finished. You do not need to share the results of the questionnaires.

<wait until participant is finished with the forms>

Anthropometry

Anthropometric assessment involves simple measurements of stature (height), and body mass (weight). You are typically required to be dressed in underclothing, and there is minimal physical discomfort associated with these measurements.

Motion capture

Passive markers are placed over the anatomical landmarks, and the reflection of infra-red light by the markers are detected by the 12 cameras around the laboratory to indicate the position and orientation of the body in 3D space.

Muscle activation

This technique is used for recording changes in the electrical potential of muscle fibers that are associated with their contraction. We are using a telemetry system that is synced with our motion capture apparatus. To improve the fidelity of the recorded signal, I need to clean your skin with soap and water, dry shave (if necessary) the electrode placement sites with a disposable razor and slightly abrade the skin with sand paper. I will rub your skin with alcohol-soaked pads to reduce impedance further. If your skin is sensitive to alcohol, please let me know, and I will skip this step. I will then attach the sensors to your muscles using an adhesive tape.

Isokinetic dynamometry

We are using an isokinetic dynamometer to measure maximum voluntary isometric contraction (MVIC) of each muscle. It allows fixing the limbs in positions that can produce maximum muscular activation. Isometric testing requires you to produce maximum force against an immovable resistance. We use the data to normalize the EMG signal to have a percentage of activity for each player. I will need to stabilize you on the device with appropriate belts or harness, to ensure that the recorded MVIC signal is generated by the joint muscles only, without any contribution from other actions. I will securely fasten the tested body segment to the arm input of the dynamometer. For each muscle, I will conduct three MVICs, and you have to progressively exert towards your maximum contraction (~2 s), maintain the effort for 5 s, and then gradually reduce the contraction (~3 s). During the MVIC, I will encourage you to exert to the maximum verbally. Real time display of your muscle contraction is also shown on the screen in front of you.

Oxygen consumption measurement
Pulmonary gas exchange variables include oxygen uptake ($\dot{V}O_2$), and gas exchange variables are measured at rest and during the activity to determine resting metabolic rate and gas exchange kinetics. This information is used to determine performance potential and to examine the effect of exercise training. I will now fit the cardiopulmonary device on you. This involves wearing the receiver and fitting the provided mask on your face. You can breathe normally once I fitted the device and mask on you. Next, I will measure your metabolic responses at rest. This involves measuring your heart rate and oxygen consumption while you are relaxing for some minutes.

Game participation
Next, you will play the swimming video game called Michael Phelps: Push the Limit. You will stand in front of the Kinect sensor and swim according to the technique. There is a video demonstration at the beginning of the game to get acquainted with the procedures. You may skip this part if you want.

Capillary blood test
Capillary blood samples (typically 5-75 µL or 1-15 small droplets) are taken from either the earlobe before, during, or after exercise testing and are conventionally used to assess pH, lactate, and bicarbonate values. Additional parameters can be measured at the discretion of the physiologist. A capillary blood sample is obtained by using a lancet device, which makes a small puncture in the skin. Gloves and lancets are single use only and are discarded after every sample. This is a simple procedure and causes only minor discomfort.

Heart Rate Monitoring
Heart rate is monitored with a specific device. A transmitter belt is worn around the chest, and the measured heart rate is transmitted to the cardiopulmonary receiver. Here is how it is fitted.
<images shown>
There is a change room in the lab. Please fit the heart rate monitor and return.

Rate of Perceived Exertion
The general aim of the rate of perceived exertion (RPE) is to quantify your subjective perception of exertion as a means of determining the activity intensity. For example, no exertion at all is sitting still, and maximal exertion is a theoretical concept of pushing the body to its absolute physical limits. I will keep the RPE scale chart in your full view during the activity and I will remind you throughout the activity to think about what sort of sensations you have while making your judgment rating.

Post-trial questionnaires
That is the end of exercise portion of this study. Could you please fill these post-trial questionnaires.
<wait for the participants to fill the questionnaires>
Thank you very much for participating in this study.

Appendix IV.5. Informed Consent Form

University of Porto, Faculty of Sport
Informed consent form for human research subjects

General Information
Study title: Virtual swimming: A psycho-biophysical evaluation of an active video game.
Person in charge of study:

Principal Investigator, PI	Student Principal Investigator, SPI
João Paulo Vilas-Boas, Ph.D.	Pooya Soltani, M.Sc.
	Ph.D. degree student in Faculty of Sport

Description of Research
You are kindly being asked to participate in "Virtual Swimming: A psycho-biophysical evaluation of an active video game," conducted at the Porto Biomechanics Laboratory (LABIOMEP) and Faculty of Sport, University of Porto. Your participation is completely voluntary. You do not have to participate if you do not want to. The purpose of this research is to characterize a sport active video game from different aspects of biomechanics, physiology, and psychology.

Study Procedures
If you agree to participate you will be asked to play a swimming exergame in the laboratory. After the game play, you will be asked to fill out questionnaires about your experience while exergaming.

Risks and Benefits
This game involves low to moderate activity, and therefore, there is a small risk of injury during the testing sessions. We will monitor your heart rate, if it exceeds 80% of estimated maximal, we will ask you to rest for 5-minutes or until your heart rate recovers to 30% of maximal. You may experience mild muscle soreness from the new exercise. Although there is minimal risk of falling, every precaution will be taken as described above. This puts any risk below what you may have during the activity. Porto Biomechanics Laboratory (LABIOMEP) and Faculty of Sport, University of Porto will not be held responsible for costs if an injury occurs. Upon completion of the study and depending on your test, free of charge reports and a debriefing letter will be provided.

Study Costs
You will not be responsible for any of the costs from taking part in this research study.

Data Storage to Protect Confidentiality
By taking part of this study, you should understand that this study collects demographic and health data, as well as digital video recording data. This data will be recorded by the study investigators who may store and process your data with electronic data processing systems. Your identity (your name, address, and other identifiers) will be kept confidential. You will have a code number, and your actual name will not be used. Only the study investigators will be able to link the code number to your name and will keep this information for a minimum of 3 years and no longer than 7 years after this study is completed.
The study investigators will examine the data to analyze the information obtained from this study, and for general health research. Your data may be used in scientific publications. If the findings from the study are published, you will not be identified by name. Your identity will be kept confidential.
The following individuals, agencies, or both will be able to look at and copy your research records: The investigator, study staff, and other medical professionals who may be evaluating the study: Authorities from the University of Porto, including the institutional review board.

Voluntary Participation and Withdrawal
If you do not sign this approval form, you will not be able to take part in this research study. You can change your mind and this approval at any time. If you change your mind, you must revoke your approval in writing. Beginning on the date that you revoke your approval, no new personal health information will be used for research. However, the study investigators may continue to use the health information that was provided before you withdrew your approval. You have the right to look at your study data at the study investigator's office and to ask for corrections of any of your data that is wrong.

Principal investigator: João Paulo Vilas-Boas, Ph.D.
Title: Virtual swimming: A psycho-biophysical evaluation of an active video game.
I (type name)   consent to participation in this psycho-biophysical assessment on the following terms:
1- I have read the Explanation of Psycho-biophysical Assessment Procedures attached and understand what I will be required to do. I have had the opportunity to ask questions and have received satisfactory explanations about the tests to be conducted.
2- I understand that I will be undertaking physical exercise at or near the extent of my capacity and there is a possible risk in the physical exercise at that level, such as episodes of transient light-headedness, fainting, abnormal blood pressure, chest discomfort, and nausea.
3- I understand that this may occur although the staff in this laboratory will take all proper care in the conduct of the assessment, and I fully assume that risk.
4- I understand that I can withdraw my consent, freely and without prejudice, at any time before, during, or after testing.
5- I have told the person conducting the assessment of any illness or physical defect I have that may contribute to the level of that risk.
6- I understand that the information obtained from the test will be treated confidentially with my right to privacy assured. However, the information may be used for statistical or scientific reasons with privacy retained.

7- I release this laboratory and its employees from any liability for any injury or illness that I may experience during the assessment as well as any subsequent injury or illness that is connected to or to any extent influenced by the assessment.
8- I will indemnify this laboratory in respect to any liability it may incur in relation to any other person in connection with the assessment.
9- I understand that I may address any questions about study participation to Pooya Soltani (111114024@fade.up.pt, +351917388140) and that ethical concerns about the study may be directed to the chair of the ethics committee at jarduarte@fade.up.pt, +351220425240.
10- I hereby agree that I will present myself for testing in a suitable condition having abided by the requirements for diet and activity prescribed to me by laboratory staff.

Participant signature
Date
Parent/guardian name (required if age less than 16)
Signature
Date
Witness name
Signature
Date

Appendix IV.6. Termo de Consentimento Informado para Crianças

U.PORTO
UNIVERSIDADE DO PORTO
FACULDADE DE DESPORTO

CENTRO DE INVESTIGAÇÃO FORMAÇÃO INOVAÇÃO E INTERVENÇÃO EM DESPORTO
CIFI2D

Universidade do Porto, Faculdade de Desporto
Termo de consentimento informado para crianças

Introdução

Olá. O seu educando foi convidado para participar num projeto de investigação realizado na Universidade do Porto. Para este estudo, pretende-se aprender mais sobre o que motiva as crianças a participar em atividade física extra. Para avaliar o grau de satisfação e a possibilidade de participação noutras atividades física e / ou natação real, as crianças serão convidadas a jogar o videojogo Xbox 360 Kinect ® Michael Phelps: Push The Limit. A criança realizará esta atividade no Laboratório de Biomecânica do Porto (LABIOMEP). A sessão durará cerca de 30 minutos. A sessão terá lugar num dos seguintes horários: entre segunda e sexta feira, entre as 10:30 e 13:00 e entre as 15:00 e 18:00, durante os meses de março, abril, maio e junho de 2013.

Se V. Exa. e o seu educando concordarem em participar, o seu educando será convidado a visitar o laboratório uma vez. O investigador responsável supervisionará a atividade da criança durante o jogo, bem como os assistentes de investigação. O educando será convidado a preencher um questionário relacionado com a satisfação na atividade física e a intenção de participar em atividade física extra e natação real. As informações recolhidas e observadas serão mantidas em sigilo. Este termo de responsabilidade explica o estudo. Por favor, leia este formulário e entre em contato com o investigador responsável (Pooya Soltani, +351 220 425 236) em caso de dúvida. O investigador responsável é estudante de doutoramento na Universidade do Porto e orientado pelo Professor Doutor João Paulo Vilas-Boas, professor catedrático de Biomecânica da Faculdade de Desporto da Universidade do Porto. Se V. Exa. concordar com a participação do seu educando neste estudo, solicita-se o preenchimento do questionário e rubrica de todas as páginas deste documento.

Informações Sobre o Envolvimento dos Participantes no Estudo

Se decidir pela participação do seu educando neste estudo, por favor, devolva o formulário de consentimento assinado e preenchido. Se o educando cumprir os requisitos de elegibilidade, ser-lhe-á enviado um segundo conjunto de questionários sobre dados demográficos, experiência em videojogos e comportamentos de atividade física. O preenchimento deste novo conjunto de questionários demorará cerca de 25 minutos. Solicita-se a entrega do questionário devidamente preenchido ao investigador responsável durante a manhã da primeira sessão agendada para o seu educando.

Será entretanto contactado via telefónica pela equipa LABIOMEP – Laboratório de Biomecânica do Porto, orientado pelo Professor Doutor João Paulo Vilas-Boas, com vista à marcação da sessão. Este contacto dar-lhe-á a oportunidade de colocar questões adicionais ou expressar qualquer preocupação que V. Exa. ou o seu educando possam em relação ao estudo. Receberá uma chamada de lembrete no dia anterior à sessão.
A sessão terá lugar no LABIOMEP – Laboratório de Biomecânica do Porto, na Faculdade de Desporto da Universidade do Porto (Rua Dr. Plácido Costa, 91 – 4200-450 Porto). O educando será acompanhado para o laboratório e ser-lhe-á solicitado consentimento verbal para prosseguir com a sessão. Esta confirmação será validada por assinatura do educando. Será solicitado ao educando que retire o calçado e permaneça em pé para medir a altura com o auxílio de um estadiómetro. Seguidamente será convidado a colocar-se numa balança eletrónica portátil para medição do peso. As medições serão realizadas por profissionais qualificados para o efeito. Caso o seu educando se encontre abaixo ou acima dos critérios de peso saudável (Índice de Massa Corporal (IMC) abaixo do 5º percentil ou acima do 85º percentil) será considerado como não elegível para a recolha de dados mas poderá participar no jogo de natação virtual.
O educando do grupo elegível iniciará a sua participação jogando o videojogo ativo “Xbox 360 Kinect Michael Phelps: Push the limit”. O procedimento do jogo será explicado ao educando e todas as dúvidas serão esclarecidas. Haverá água disponível para os participantes e ser-lhe-á solicitado o preenchimento de um questionário sobre o seu nível de satisfação durante a atividade. No final do jogo, o educando será convidado a classificar a sua satisfação com a atividade.
Será concedido um período de aquecimento de 5 minutos para permitir a familiarização com o jogo. Após o aquecimento, o educando jogará o videojogo ativo durante 15 minutos.

Riscos

Caso o participante siga as instruções de jogo dadas pelo investigador responsável, estará sujeito a um risco mínimo. Não estão descritos riscos em comportamentos normais de jogo. Uma criança com condição médica conhecida (por exemplo, doença cardiorrespiratória, metabólica, ou condição doença ortopédica ou doença) não será elegível para participar do estudo. Se o seu educando for muito ativo fisicamente durante estas sessões, poderá sentir algumas dores musculares um ou dois dias após a atividade. Uma equipa de profissionais treinados para o efeito estará presente para garantir que o seu educando exerce toda a atividade em segurança.

Benefícios

O participante terá o benefício de jogar o novo videojogo ativo “Xbox 360 Kinect® Michael Phelps: Push the limit”. O investigador beneficiará de um ambiente controlado para recolha de informação relevante para o avanço no conhecimento acerca de comportamentos de atividade física pediátrica.

Confidencialidade

Todas as informações recolhidas durante o estudo serão mantidas em sigilo. Um código único será utilizado para identificar cada participante sem referências a nomes de pessoas, endereços ou números de telefone. Não serão feitas referências em relatórios orais ou escritos que possam vincular os participantes ao estudo. Todas as informações serão armazenadas em segurança. Os investigadores do projeto serão as únicas pessoas com acesso a informações do participante. Uma vez terminado o estudo, as informações de cada participante serão devidamente destruídas. Os procedimentos de proteção de confidencialidade serão aprovados pela Comissão Ética da Universidade do Porto para garantir o cumprimento das normas de proteção de sujeitos humanos.

Compensação

Um certificado oficial de participação será concedido a todos os participantes.

Tratamento Médico de Emergência

Os participantes não estarão cobertos por um seguro de saúde da Universidade do Porto, pelo que esta entidade não reembolsará quaisquer reivindicação médicas ou outras compensações. Se alguma lesão for realizada no decorrer na atividade (ou em caso de dúvida) contacte o investigador responsável (Pooya Soltani, (+351) 220 425 236). Em caso de emergência entrar-se-á em contacto com a Linha Europeia de Emergências (112).

Informações de Contacto

Se tiver quaisquer dúvidas sobre o estudo e procedimentos ou o seu educando sentir efeitos adversos como resultado de sua participação neste estudo, por favor contacte o investigador principal, Pooya Soltani (Laboratório de Biomecânica da Faculdade de Desporto, Rua Plácido Costa 91, Porto, Portugal. Telefone: (+351) 220 425 236).

Participação

A sua participação neste estudo é voluntária, pelo que pode recusar-se a prosseguir com a sua participação a qualquer momento, sem quaisquer repercussões. Se decidir retirar-se do estudo, todos os dados relativos à participação do seu educando serão destruídos.

Consentimento

Declaro que li as informações constantes nas páginas anteriores deste documento. Declaro que recebi uma cópia deste termo do consentimento. Concordo com a participação do meu educando neste estudo.

Informação de Contacto

Nome do educando:
Nome do Encarregado de Educação:
Telefone
Casa: Telemóvel: Trabalho:
Morada: Email:

Assinatura do encarregado de educação
Data
Assinatura do Investigador Principal
Data

Appendix IV.7. Questionário de Elegibilidade

A ser preenchido pelo encarregado de educação
Se tiver fornecido o consentimento para a participação do seu educando neste estudo, responda por favor às seguintes perguntas para garantir que o educando é elegível para o estudo.

Inormações Demográficas Encarregado de Educação
Por favor, preencha este questionário se for o encarregado de educação principal da criança envolvida neste estudo.
1. Idade da criança:
2. Sexo da criança: ○ Masculino ○ Feminino ○ Outros
3. Altura da criança: m cm.
4. Peso da criança: kg.
5. O seu educando tem algum problema de saúde que limite a sua capacidade de participar neste estudo (isto é, doeança cardiorrespiratória, metabólica ou ortopédica)?

3. Relação com a criança
○ Mãe (biológico, adotiva, madrasta) ○ Pai (biológico, adotivo, padrasto)
○ Avó ○ Avô ○ Tia ○ Tio ○ Irmã ○ Irmão ○ Primo ○ Guardião legal
Outros (especifique):
4. Educação: verifique anos de escola completou. (marque apenas uma resposta)
○ Ensino primário (4 anos ou menos) ○ Ensino básico (5-9 anos)
○ Ensino secundário (10-12 anos) ○ Ensino profissional
○ Ensino Superior – Licenciatura ○ Ensino Superior – Mestrado ou Doutoramento
5. Estado civil:
○ Casado ○ Separado ○ Divorciado ○ Viúvo ○ Solteiro ○ União de facto
Outros (especifique):

Questionário Atividade Física e Televisão
Por favor, circule a resposta para cada pergunta que melhor descreve os hábitos do seu educando.
1. Num dia de semana normal, em média, durante quantas horas por dia o seu educando visualiza televisão, vídeo, DVD ou computador (excluindo o uso escolar)?
○ 1 hora ou menos ○ 2 horas ○ 3 horas ○ 4 horas ○ 5 horas ou mais
2. Num dia de fim de semana normal, em média, durante quantas horas por dia o seu educando visualiza televisão, vídeo, DVD ou computador (excluindo o uso escolar)?
○ 1 hora ou menos ○ 2 horas ○ 3 horas ○ 4 horas ○ 5 horas ou mais
3. Com que frequência é que o seu educando assiste programas de televisão / DVD / vídeo / computador durante o horário das refeições?
○ 1 hora ou menos ○ 2 horas ○ 3 horas ○ 4 horas ○ 5 horas ou mais
4. O seu educando possui alguma televisão no quarto? ○ Sim ○ Não

Por favor, circule a resposta para cada pergunta que melhor descreve hábitos de atividade física do seu educando.

5. Quão ativo é o seu educando em comparação com outras crianças da mesma idade?

○ Muito menos ativo ○ Um pouco menos ativo ○ Igualmente ativo

○ Um pouco mais ativo

6. Quantas vezes, numa semana típica, incluindo dias de semana e fins de semana, o seu educando pratica atividade física suficiente para transpirar e respirar intensamente?

○ Mais do que uma vez por dia ○ Diariamente ○ 5-6 dias / semana

○ 3-4 dias / semana ○ 1-2 dias / semana ○ < 1 dia / semana

○ Nunca

7. O meu educando prefere assistir televisão ou brincar dentro de casa do que brincar no exterior.

	1	2	3	4	5	6	7	
Completamente verdadeiro	○	○	○	○	○	○	○	Completamente falso

8. Num dia de semana normal, quantas horas o seu educando brinca em exteriores?

Horas:

9. Num dia de fim de semana normal, quantas horas o seu educando brinca em exteriores?

Horas:

Experiência com Videojogos Ativos

Por favor, preencha este questionário se for o encarregado de educação principal da criança envolvida neste estudo.

1. O meu educando tem experiência a jogar Xbox 360 Kinect. ○ Sim ○ Não

1a. Se respondeu "Sim", por favor, liste todos os jogos do educando tem experiência anterior de jogo.

2. O meu educando tem experiência no videojogo Xbox 360 Kinect, Michael Phelps: Push the Limit. ○ Sim ○ Não

3. O meu educando tem experiência noutros sistemas de videojogos ativos, tais como:

Nintendo® Wii, Sony EyeToy™ ou Dance Dance Revolution®. ○ Sim ○ Não

3a. Se respondeu "Sim", por favor, liste todos os sistemas de videojogos ativos em que o seu educando tem experiência.

4. Se respondeu "Sim" à pergunta 3, por favor liste os videojogos (por exemplo, Wii® Sports, Nicktoons: Movin'™) em que o seu educando tem experiência que pertençam a outros sistemas de videojogos ativos (por exemplo, Nintendo® Wii, Sony EyeToy™ ou Dance Dance Revolution).

Appendix IV.8. Formulário de Consentimento do Educando

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I. É necessária a obtenção de consentimento para a participação de crianças (idade inferior ou igual a 17 anos) em estudos de investigação. O consentimento deve ser obtido para além do consentimento do encarregado de educação.

Quem somos?

Chamo-me Pooya Soltani e sou do Irão. Estou a realizar um projeto especial para o meu trabalho na Faculdade de Desporto da Universidade do Porto. Um dos meus professores, Professor Doutor João Paulo Vilas-Boas, está a ajudar-me a terminar o meu projeto de investigação.

Por que estamos a contactar contigo?

Queremos falar-te sobre o nosso projeto para saber se gostavas de nos ajudar.

Para que serve este estudo?

Queremos aprender mais sobre o que leva as pessoas a jogar videojogos ativos. Gostaríamos de ver se estes jogos te podem motivar a fazer mais exercício ou até mesmo a praticar uma atividade física real, como a natação.

O que te vai acontecer se decidires participar neste estudo?

Se decidires ajudar neste projeto, virás ao laboratório aqui na Universidade do Porto uma vez. Nesse dia, tu e o teu Encarregado de Educação vão saber mais sobre o projeto e vais dizer-nos se queres participar. Se quiseres participar, vamos medir a tua altura e pesar-te. Antes de jogar, vamos fazer-te algumas perguntas sobre como te sentes sobre fazer exercícios e natação. Depois disso, vamos convidar-te a jogar um jogo de natação. Terás de ficar em frente à televisão e balançar os braços para nadar. Quando terminares o jogo, vamos fazer-te mais algumas perguntas para saber de gostaste de jogar o videojogo e damos-te um certificado de participação.

Quais são as coisas boas ou más que podem acontecer?

Os teus braços e pernas podem ficar cansados se não estiveres habituado a actividade e também podem ficar doridos no dia seguinte do jogo. É normal.

Serás obrigado a participar no projeto?

Não. Ninguém vai ficar aborrecido contigo se não quiseres participar. Basta dizer-nos que não queres. E lembra-te, podes mudar de ideias mais tarde, se decidires que não queres participar mais.

Tens alguma dúvida?

Podes fazer perguntas a qualquer momento. Podes perguntar agora. Podes perguntar depois. Podes falar comigo ou com outra pessoa, a qualquer momento

durante o estudo. Aqui estão os números de telefone para entrar em contacto connosco:
Professor Doutor João Paulo Vilas-Boas, Laboratório de Biomecânica, (+351) 220 425 236.
Laboratório de Biomecânica do Porto, (+351) 220 425 237.
Se quiseres participar no estudo, assina o teu nome na linha abaixo:

Assinatura da Criança
Data
Assinatura do pai / responsável
Data
Assinatura do investigador
Data

II. O examinador utilizará os seguintes procedimentos durante o teste:

- Manter uma expressão facial agradável.
- Dar encorajamento verbal através de observações tais como:
  "Bom trabalho!"
  "Força!"
  "Continua assim, estás a ir bem!"
  "Vamos lá, é o último esforço!"

III. O examinador vai utilizar os seguintes procedimentos no final do teste:

- Se a criança desejar parar durante o teste, o examinador manterá uma expressão neutra, encerrar o material de teste e dizer: "Tudo bem, obrigado novamente pela tua colaboração. Vamos voltar para a sala de entrada."
- Ao concluir o teste, o examinador dirá: "Obrigado novamente pela tua colaboração. Estiveste muito bem! Vamos voltar para a sala de entrada."

IV. Estas diretrizes de gestão comportamental serão seguidas durante o teste:

- As instruções incluirão frases como:
  "Por favor, continua a ouvir com atenção."
  "Por favor, espera até eu terminar a pergunta antes de dar a tua resposta."
  "Por favor, mantem-te atento."
- Se a criança é incapaz de prosseguir a sua participação no estudo, a administração do mesmo será descontinuada.

Appendix IV.9. Physical Activity Enjoyment Scale (PACES) and Activity/Sport Intention Questionnaire

Please rate how you feel at the moment about the physical activity you have just been doing.

	1	2	3	4	5	6	7	
I enjoy it.	○	○	○	○	○	○	○	I hate it.
I dislike it.	○	○	○	○	○	○	○	I like it.
It is no fun at all.	○	○	○	○	○	○	○	It is a lot of fun.
I feel good physically doing it.	○	○	○	○	○	○	○	I feel bad physically while doing it.
I am very frustrated.	○	○	○	○	○	○	○	I am not frustrated by it at all by it.

	Not likely at all 1	2	3	4	5	6	Very likely 7
If I had a chance, I would participate in physical activity later today.	○	○	○	○	○	○	○
If I had a chance to participate in physical activity, I would choose swimming.	○	○	○	○	○	○	○

Appendix IV.10.Game Usability Scale Questionnaire

This questionnaire is for measuring perceptions of usability.

	Strongly disagree 1	2	3	4	Strongly agree 5
1- I think that I would like to play this game frequently.	○	○	○	○	○
2- I found the game unnecessarily complex.	○	○	○	○	○
3- I thought the game was easy to play.	○	○	○	○	○
4- I think that I would need the support of a technical person to be able to play this game.	○	○	○	○	○
5- I found the various functions in this game were well integrated.	○	○	○	○	○
6- I thought there was too much inconsistency in this game.	○	○	○	○	○
7- I would imagine that most people would learn to play this game very quickly.	○	○	○	○	○
8- I found the game very cumbersome to play.	○	○	○	○	○
9- I felt very confident playing the game.	○	○	○	○	○
10- I needed to learn a lot of things before I could get going with this game.	○	○	○	○	○

	Worst quality 1	2	3	4	5	6	7	8	9	Excellent quality 10
11- Please rate the overall quality of the game.	○	○	○	○	○	○	○	○	○	○

Appendix IV.11. Game Experience Questionnaire

The purpose of the present measure development project is to identify players' typical level of psychological engagement in playing video games.
When I am playing the game, ...

	Not at all 1	2	3	4	Extremely 5
1- I lose track of time.	○	○	○	○	○
2- Things seem to happen automatically.	○	○	○	○	○
3- I feel different.	○	○	○	○	○
4- I feel scared.	○	○	○	○	○
5- The game feels real.	○	○	○	○	○
6- If someone talks to me, I don't hear them.	○	○	○	○	○
7- I get wound up.	○	○	○	○	○
8- Time seems to kind of stand still or stop.	○	○	○	○	○
9- I feel spaced out.	○	○	○	○	○
10- I don't answer when someone talks to me.	○	○	○	○	○
11- I can't tell that I'm getting tired.	○	○	○	○	○
12- Playing seems automatic.	○	○	○	○	○
13- My thoughts go fast.	○	○	○	○	○
14- I lose track of where I am.	○	○	○	○	○
15- I play without thinking about how to play.	○	○	○	○	○
16- Playing makes me feel calm.	○	○	○	○	○
17- I play longer than I meant to.	○	○	○	○	○
18- I really get into the game.	○	○	○	○	○
19- I feel like I just can't stop playing.	○	○	○	○	○

Appendix IV.12. Rate of Perceived Exertion Chart

This scale was used to indicate the perception of effort during the exergame play. It is your feeling of effort and exertion that is important, not what other people think. Look at the scale and the expressions and point to one of the numbers when required.

0	nothing at all	
0.5	very, very weak (just noticeable)	
1	very weak	
2	weak	(light)
3	moderate	
4	somewhat strong	
5	strong	(heavy)
6		
7	very strong	
8		
9		
10	very, very strong	(almost max)
•	maximal	

Proper instruction in the use of this scale is important. Subjects should lead to understand the interpretation of the descriptive terms that coincide with the numbers. Note that some subjects may be confused with the terms "weak" and "strong". They may report how they feel at a certain level of effort ("I feel week here" or "I feel strong here") instead of correctly reporting sensations of discomfort (weak discomfort or strong discomfort), resulting from the level of exertion.

Appendix IV.13. Notice of Committee Action

U.PORTO
UNIVERSITY
OF PORTO
FACULTY
OF SPORT

Ethics Committee

Process CEFADE 01/2013
Project title: Virtual Swimming: A psycho-biophysical evaluation of an active video game.
Project type: New Project
Researcher(s): Pooya Soltani
Faculty: Faculty of Sport
Funding agency/sponsor: N/A
Period of approval: 2013-11-01 to 2015-10-01

The Ethics Committee of the Faculty of Sport from the University of Porto analyzed the project entitled “Virtual Swimming: A psycho-biophysical evaluation of an active video game.” presented by Pooya Soltani, M.Sc. in accordance with university guidelines to ensure adherence to the following criteria:

• The risks to subjects are minimized.
• The risks to subjects are reasonable in relation to the anticipated benefits.
• The selection of subjects is equitable.
• Informed consent is adequate and appropriately documented.
• Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
• Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
• Appropriate additional safeguards have been induced to protect vulnerable subjects.

Considering the project’s characteristics, as well as the competence of the research team, the Ethics Committee addresses a positive opinion, because the ethical principles that govern this type of scientific work are respected.

The chairman of the Ethics Committee,
José Alberto Ramos Duarte
[Signature is available in the printed version]
Porto and Faculty of Sport, 27th October 2013.

Appendix IV.14. Letters of Copyright Permission

To: Permission department of the publisher
Attached: Publisher's permission form (where applicable)

To whom it may concern,
I am a Ph.D. candidate of Sport Science at Faculty of Sport, University of Porto, Portugal. I am preparing my doctoral (Ph.D.) thesis, which is intended to be a compilation of an overall summary (overview) and research papers – bound together.
I would greatly appreciate your permission to include:
NAME OF PUBLICATION
Yours sincerely,
Pooya Soltani

Appendix IV.15. Flyer

This flyer was distributed in print and online to call for study participants.

LABORATÓRIO DE BIOMECÂNICA DO PORTO
U.PORTO

PLAY

XBOX

WITH US

Pooya Soltani
João Paulo Vilas-Boas

Virtual Swimming: A psycho-biophysical evaluation of an active video game.

What will you have to do? Initial assessment (body composition, resting metabolic rate, maximum voluntary isometric contraction, baseline lactate), questionnaires on gaming habits, swimming exergame participation with psycho-biophysical evaluation (kinematics of movement, muscle activation, energy expenditure, enjoyment, usability, and game experience)

Compensation: Depending on your evaluation, test reports will be provided free of charge.

Questions? Principal investigator: João Pualo Vilas-Boas (jpvb@fade.up.pt)

Student principal investigator: Pooya Soltani (111114024@fade.up.pt)

This research project has been approved by the Ethics Committee of Faculty of Sport, University of Porto (Process number: CEFADE 01/2013).

Figure AIV. 1. Flyer

Appendix IV.16. Flyer Recrutamento

This flyer was distributed in print and online to call for study participants.

Figure AIV. 2. Flyer recrutamento.

Appendix IV.17. Debriefing Letter

UNIVERSITY OF PORTO FACULTY OF SPORT

CENTRE OF RESEARCH EDUCATION INNOVATION & INTERVENTION IN SPORT CIFI2D

PORTO BIOMECHANICS LABORATORY LABIOMEP

Debriefing Letter
Virtual Swimming: A psycho-biophysical evaluation of an active video game.

Thank you very much for your participation in this study. Now that you have completed the experiment, the examiner will answer any questions you may have.
During the session, you played a swimming active video game (exergame).

One of our objectives is to compare movement patterns of sport exergames in players with different gender, exergaming, and real sport background. We hypothesize that players with real swimming experience would swim close to real swimming while playing the game. These results will allow us to understand whether we can use sport exergames as means of an educational tool. Another objective is to see measure energy expenditure while sport exergaming accurately, and to compare activity profiles of players. The results of this study can show us if sport exergames can be used as training tools. Another objective is to measure muscle activation of swimming exergame to check if playing these games are safe. Finally, we would like to know if playing sport exergames can encourage players to participate in real sport and more physical activity.

We expect to publish the results of our studies in journals and conferences in the near future.

We thank you once again for participating in this study. If you have further questions, please contact Pooya Soltani (111114024@fade.up.pt) or João Paulo Vilas-Boas (jpvb@fade.up.pt, +351220425236). If you have ethical concerns regarding the study, please contact the chair of the ethical committee at jarduarte@fade.up.pt, +351220425240.

Appendix IV.18. Sequencing the procedures in each study

Kinematic

1- Calibration of motion capture system to the measurement volume.
2- Signing informed consent.
4- Pre-trial questionnaires.
4- Measuring body composition (Height and weight).
5- Getting familiar with the system and the game
6- Placing markers over anatomical landmarks.
7- 10 s static trial for each subject standing in anatomic position.
8- Playing the game.
9- removing the markers.
10- Post-trial questionnaires.

Muscle activation

1- Signing informed consent.
2- Pre-trial questionnaires.
3- Measuring body composition (Height and weight).
4- Getting familiar with the system and the game
5- Preparation of skin (shaving (if necessary), lightly abrading, and cleaning with an alcohol swab).
6- Placement of the electrodes
7- MVIC measurements using dynamometer
8- Placing markers over anatomical landmarks.
9- 10 s static trial for each subject standing in anatomic position.
10- Playing the game.
11- removing the markers.
12- Post-trial questionnaires.

Energy expenditure

1- Signing informed consent.
2- Pre-trial questionnaires.
3- Measuring body composition (Height and weight).
4- Getting familiar with the system and the game
5- Setting up the device and attaching the mask and heart rate monitor.
6- Measuring VO_{2rest}, HR_{rest}, and BLa_{rest}.
7- Setting up the video camera.
8- Playing the game.
9- Measuring BLa and RPE after each technique.
10- Post-trial questionnaires.
11- Measuring BLa a 3, 5, and 7 min following the activity.
12- Disassembling the gas analyzer after 15 minutes.

Psychology

1- Signing informed consent.
2- Pre-trial questionnaires.
3- Future PA and real swimming participation intentions.
4- Getting familiar with the system and the game
5- Completing sPACES, GEQ, and SUS.
6- Future PA and real swimming participation intentions.