Citation for published version:
Soltani, P, Figueiredo, P, Fernandes, RJ & Vilas-Boas, JP 2017, 'Muscle activation behavior in a swimming exergame: Differences by experience and gaming velocity', *Physiology and Behavior*, vol. 181, pp. 23-28. https://doi.org/10.1016/j.physbeh.2017.09.001

DOI:
10.1016/j.physbeh.2017.09.001

Publication date:
2017

Document Version
Peer reviewed version

VOLUME 181 1 NOVEMBER 2017 ISSN 0031-9384

Physiology & Behavior

EDITOR-IN-CHIEF:
Thomas Luts

Muscle activation behavior in a swimming exergame: Differences by experience and gaming velocity

Pooya Soltani[a,b,c], Pedro Figueiredo[d], Ricardo J. Fernandes[a,c], João Paulo Vilas-Boas[a,c]

[a] *Center of Research, Education, Innovation and Intervention in Sport (CIFI2D), Faculty of Sport, University of Porto, Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal*
[b] *Department of Physical Education and Sport Sciences, School of Education and Psychology, Shiraz University, Pardis-e-Eram, Eram Square, 71946-84759 Shiraz, Iran*
[c] *Porto Biomechanics Laboratory (LABIOMEP), Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal*
[d] *Department of Kinesiology, University of Maryland, College Park, MD, USA*

Abstract

The effects of playing intensity and prior exergame and sport experience on the activation patterns of upper limb muscles during a swimming exergame were investigated. Surface electromyography of Biceps Brachii, Triceps Brachii, Latissimus Dorsi, Upper Trapezius, and Erector Spinae of twenty participants was recorded, and the game play was divided into normal and fast. Mean muscle activation, normalized to maximum voluntary isometric contraction (MVIC), ranged from 4.9 to 95.2%MVIC and differed between normal and fast swimming for all techniques ($p < 0.05$), except for Latissimus Dorsi during backstroke. After normalizing the %MVIC to playing velocity, selective behaviors were observed between muscles which were sufficient for pragmatic game play. Moreover, prior exergame and real sport experience did not have any effect on the muscle activation changes between normal and fast swimming. These behaviors are likely to happen when players understand the game mechanics, even after a short exposure. Such evaluation might help in adjusting the physical demands of sport exergames, for safe and meaningful experiences.

Keywords: Virtual swimming; Surface electromyography; Kinematics; Exergame

Introduction

Exergames provide ample opportunities to play virtual sports aiming to increase physical activity levels and to improve motor skills and performance capabilities [7], [26]. Previous research confirmed that neck and upper limbs muscle activations are higher during exergaming compared to sedentary games [16], and subjects have higher muscle activity when playing against a human opponent than a computer counterpart [23]. Electromyography (EMG) related studies try to capture the emotional and physical reactions to game events [20], which could be used to control the movements in computer games [24], or to measure unconscious emotional expressions; for example, increased activation of Zygomaticus Major and Corrugator Supercilii muscles are related to positive and negative emotions, respectively [25].

While challenges in sedentary games are usually controlled by adjusting the complexity of mental tasks, employing body movements 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 [6], [27]. Moreover, although earlier studies provided convincing results regarding increased energy expenditure compared to sedentary gaming [12], 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 [3].

As different types of feedback, competitiveness, and learning effects may contribute to exergame engagement [16], rapid responses of EMG have become a proper objective tool in recognition of players' preferable actions and behaviors, and might be useful in scenario development of video games [9]. With higher exergame engagement, muscle activation levels also increase [16], [29], and speed-based exergames might be employed to create physical demand and to avoid boredom when players' engagements diminish. 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 [4].

Although these low-cost and commercially available gaming platforms look promising (e.g., short-term increase in energy expenditure and rehabilitation), still little is known about muscle activation during exergame play. While the chance of low-effort playing exists, it is also not clear if playing at higher speeds leads to higher muscle activation. Moreover, few studies have been performed to determine muscle activation (relative to maximum voluntary isometric contraction – MVIC – and with regard to movement velocity) of upper limbs and trunk during exergame playing. It is also important to check how participants with prior real sport experience, play related sport exergames. Therefore, the purpose of this study was to assess muscle activation levels elicited during a swimming exergame with two different playing velocities in players with different exergame and real sport experience.

Methods

Twenty male college students (mean ± SD 24.2 ± 3.1 years 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 conducted according to the declaration of Helsinki, imposing that, prior to testing, participants signed a written informed consent.

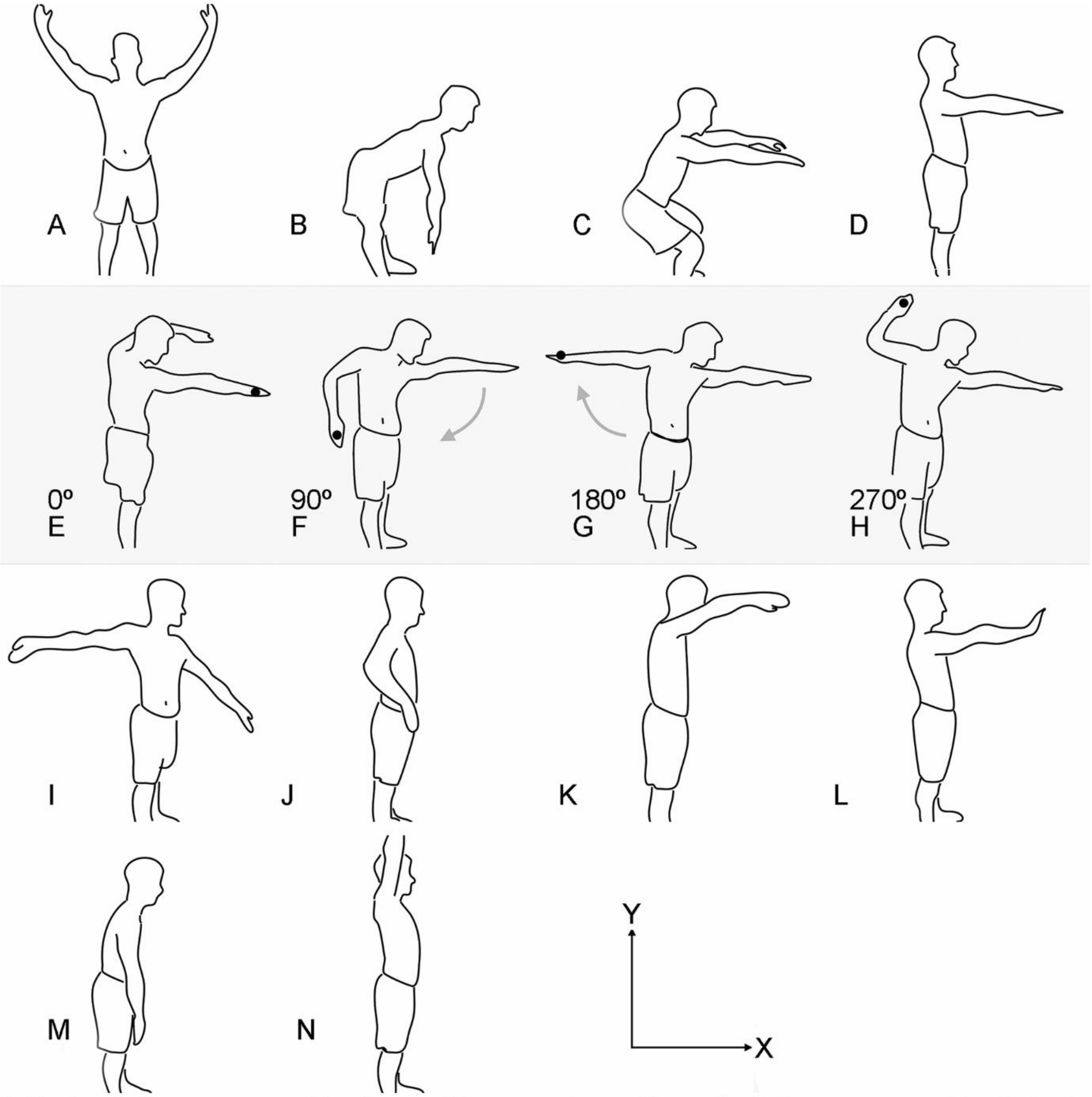
Muscle activations of the Biceps Brachii (BB), Triceps Brachii (TB), Upper Trapezius (UT), Latissimus Dorsi (LD), and Erector Spinae (ES) of the preferred limb (and side) were recorded using a Trigno™ wireless surface EMG apparatus (Delsys, USA) with a common mode rejection ratio of > 80 dB, input impedance of 1012 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 [17] and hypothesized activation during this exergame (ES). Electrodes were placed according to SENIAM project [10] and, for LD and BB, we adapted the procedures from Lehman et al. [14]. Placement sites were shaved (if necessary), lightly abraded, and cleaned with an 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 × 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 and TB was performed according to Gennisson et al. [8] and Lategan and Krüger [13], respectively. For UT and LD, we followed Hong et al. [11], and for ES, we used the procedures of Moreau et al. [21]. 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 [1]. 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, MVIC of the filtered signal was also divided by the average velocity [16] during each gaming phase, using the following equation:

True normalized EMG = RMS expressed as %MVIC / Average velocity

Three-dimensional kinematics was 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. [22]): 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. 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 1, panel 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 1, panel E; 0°), followed by the time when it is at lowest Y coordinate (Figure 1, panel F; 90°), continues to the lowest X coordinate (Figure 1, panel G; 180°), reaches the highest Y-coordinate (Figure 1, panel H; 270°), and ends up in the same maximum X coordinate to start a new cycle.



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.

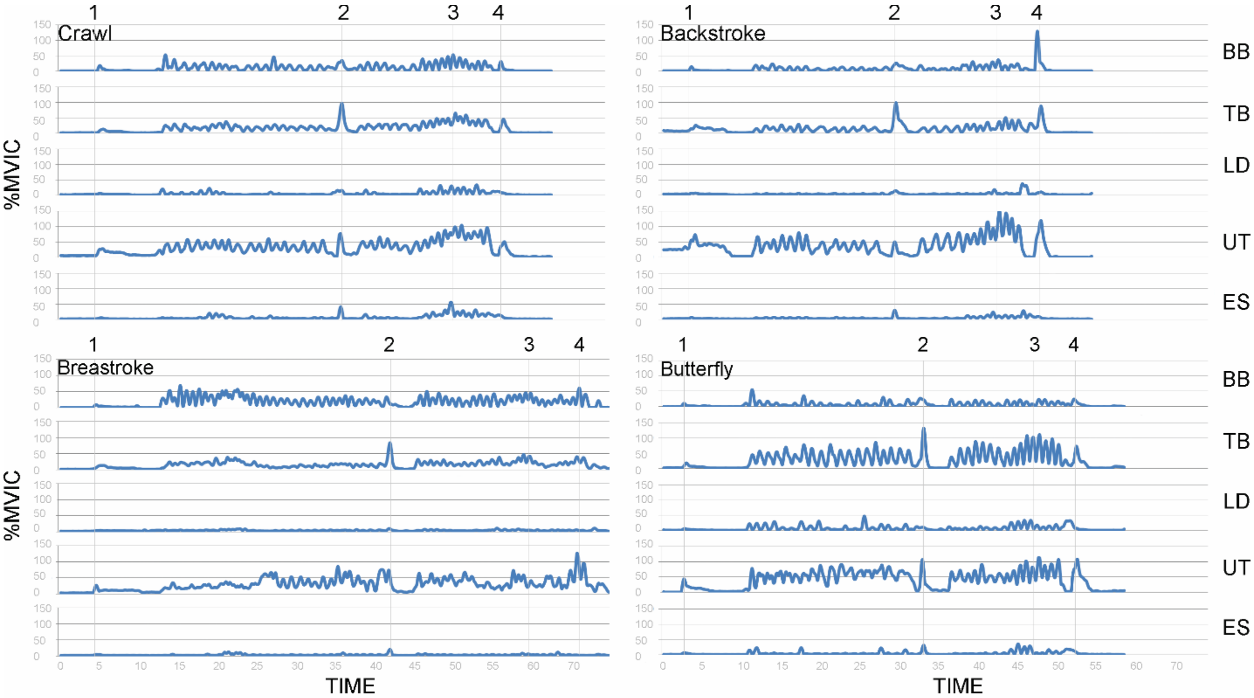
Figure 1. Body positions during different events.

Participants played with a swimming exergame (order: front crawl, backstroke, breaststroke, and butterfly; 100 m each) 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 1, panel A). During the front crawl, breaststroke, and butterfly events, subjects had to stand in front of Kinect and bend forward (Figure 1, panel B) and, after the visual command, they had to return to standing position with upper limbs at 90° of shoulder flexion (Figure 1, panel D). For the backstroke event, subjects had to hold their upper limbs in front with knees slightly bent (Figure 1, panel C) and then raise their upper limbs above their heads while extending their knees (Figure 1, panel N). Afterwards, subjects had to swing their upper limbs (Figure 1, panels E to H for front crawl; I, J, and K for backstroke, breaststroke, and butterfly, respectively) to move the avatar inside the game. For starting the second lap, players had to extend their upper limb sharply (Figure 1, panel 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 1, panel M) and then raise one to finish the race (Figure 1, panel N). Those who had experience with exergames were considered as gamers and those who knew at least two real swimming techniques were considered as swimmers. The rationale for this was that while the legs movements were not employed in this game, in most of the techniques the arms had to travel out and over the “water.” Knowing this illustrates some in the techniques helping players to move between the techniques with confidence.

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 the cut-off frequency between 20 and 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. A Levene's test verified the equality of variances in the sample (homogeneity of variance) ($p > 0.05$), and a Shapiro-Wilk test was used to test normality of the distribution ($p > 0.05$). Following that, a paired t-test was used to determine if there is any difference between the five muscles in normal and fast swimming modes. General linear model was also used to explore the effects of prior exergame and real sport experience on the EMG differences between normal and fast game play. 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 [2].

Results

Figure 2 presents a typical pattern of EMG in each swimming technique for one subject.



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 2. Time sequencing of EMG in different techniques normalized to %MVIC.

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. Table 1, Table 2 provide mean ± SD RMS EMG data, normalized to both MVIC and average velocity, respectively.

Table 1. EMG levels (normalized to %MVIC) during exergame for all muscles in two playing 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
Backstroke	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
Breaststroke	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. Biceps brachii (BB), triceps brachii (TB), latissimus dorsi (LD), upper trapezius (UT), erector spinae (ES).

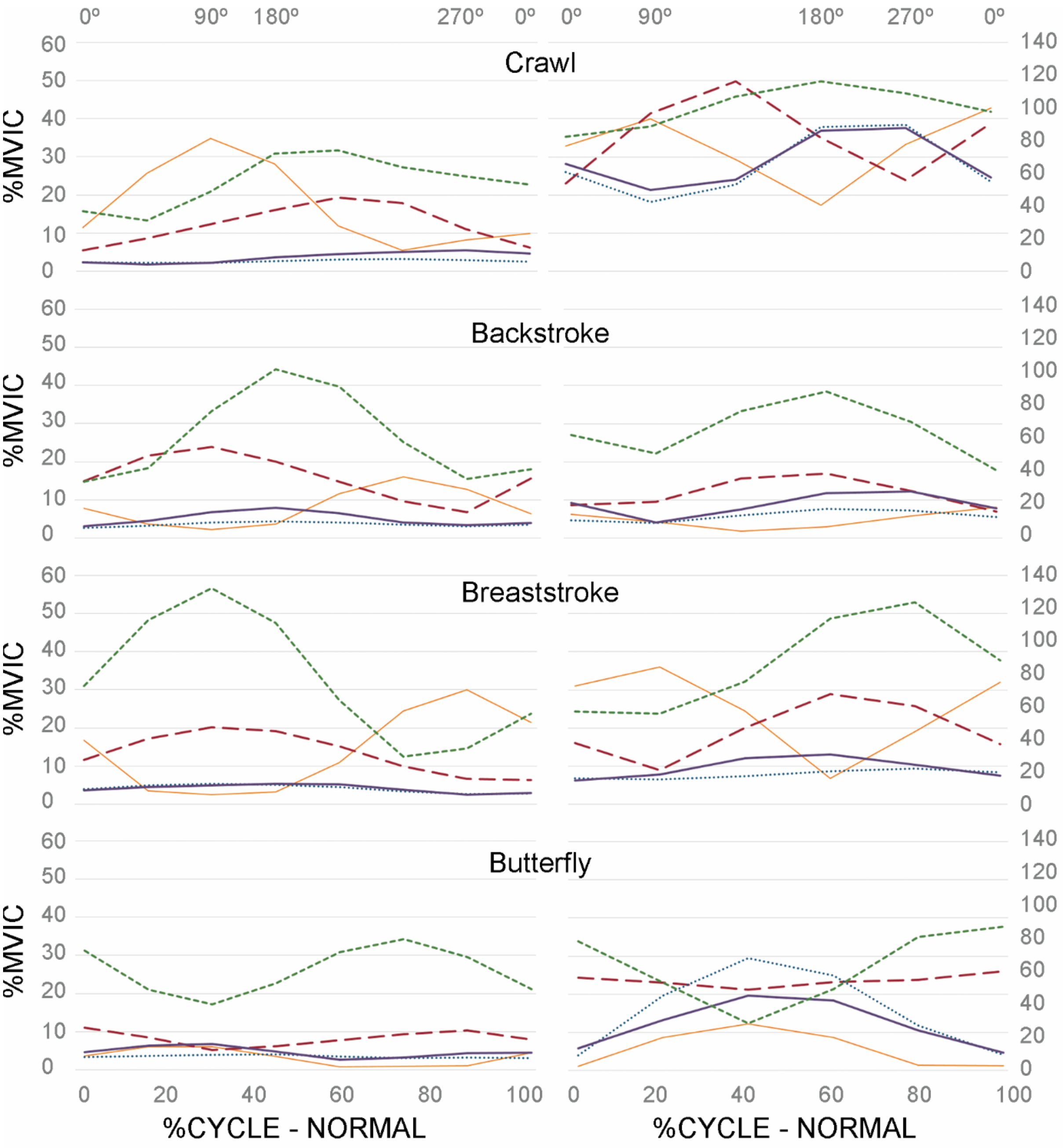
The paired *t*-test showed differences between normal and fast swimming between muscles for all techniques ($p < 0.05$; $d > 0.5$ during front crawl, $0.3 < d < 0.9$ during backstroke, and $0.3 < d < 0.6$ during breaststroke and butterfly), except in LD during backstroke ($p > 0.05$). After normalizing the %MVIC to gaming velocity, differences were observed in slow and fast gaming phases for LD and ES during crawl ($t(19) = -3.008$, $p = 0.007$, $d = 0.4$; $t(19) = -3.645$, $p = 0.002$, $d = 0.6$, respectively), BB and ES during backstroke ($t(19) = -2.312$, $p = 0.032$, $d = 0.3$, and $t(19) = -5.105$, $p = 0.000$, $d = 0.3$, respectively), LD during breaststroke ($t(19) = -2.146$, $p = 0.045$, $d = 0.3$,), and BB, LD, and ES during butterfly ($t(19) = -4.491$, $p = 0.000$, $d = 0.2$; $t(19) = -2.836$, $p = 0.011$, $d = 0.2$; and $t(19) = -3.235$, $p = 0.004$, $d = 0.8$, respectively). Prior gaming and sport experience did not affect the EMG differences between normal and fast game play ($p > 0.05$).

Table 2. %MVIC muscle activation levels (normalized to velocity) during swimming exergame for all muscles.

		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. Biceps brachii (BB), triceps brachii (TB), latissimus dorsi (LD), upper trapezius (UT), erector spinae (ES).

As shown by the investigation of muscular coordination in Figure 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 (180° to 0°) 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 3. EMG patterns in one cycle during normal and fast gaming phases 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. 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.

On the other hand, when %MVIC was normalized to playing velocity, differences were observed for LD and ES during crawl, BB and ES during backstroke, LD during breaststroke, and BB, LD, and ES during butterfly. These muscles are responsible for pragmatic game play; meaning that during the fast game play, players were playing (activating muscles) in a way to win the game and not to swim correctly. During the front crawl, LD assists in lowering the hands and activation of ES is concurrent with the rotation of the body to bring the upper limbs backward. During fast swimming, as subjects were switching from 0° to 90° in a shorter time, they were using LD and ES intentionally more while rotating their body to start the new cycles faster, leading to higher activation.

During backstroke, BB acts as an elbow flexor, bringing the upper limb down before transiting into a new cycle (middle of 90° to 0°). During the fast swimming, subjects were returning from 180° to 90° in a shorter time, leading to higher ES activity. During breaststroke and fast game play, LD joins in and pulls the arm and hand into the midline of the body and from 90° to 180° and with the help of paraspinal muscles (including ES), the player goes forward and upward. 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 180° to 0° in shorter times, requiring lowering upper arm (elbow) faster compared to normal swimming. During butterfly, most of the propulsion is done by gravity, and LD activation acts as the primary mover. Similar to breaststroke, butterfly lacks the body roll, the ES activation happens only from 0° to 90° bringing the entire upper torso 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 (elbow flexor), ES, and LD compared to normal swimming.

Although sport exergames may not produce as much muscle activation as real activity [29], such activities might still benefit participants to develop muscular endurance [19], especially when participation in real sport is not possible or practical due to disability, fear, or injury. Subjects might use wearable weights on their upper limbs to make the activity more demanding. 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 [5]. To prevent significant learning that might lead to activity reduction, variety and complexity should also be considered in the design phase [28]. 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 and/or between different testing sessions [18]. While RMS was previously used to represent the amplitude of EMG [15], we used MVIC to normalize the percentage of muscle activation of subjects, relative to their maximum effort. It should also 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 familiarize 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 in some muscles, even if the platform does not allow technical game play. Overall, although sport exergames may not completely replace practicing real sports, PE instructors should balance entertainment, game mechanics, duration, intensity, and educational elements to effectively use such sport exergames in their practice.

Conflict of interest: None declared.

References

Burden, A. (2008) Surface electromyography. In: C. Payton, & R. Bartlett (Eds.), Biomechanical evaluation of movement in sport and exercise: The British association of sport and exercise sciences guide (pp.77-102). London: Routledge.

Cohen, J. (1992). A power primer. *Psychological Bulletin*, 112(1), 155-159. doi: 10.1037/0033-2909.112.1.155

Converse, H., Ferraro, T., Jean, D., Jones, L., Mendhiratta, V., Naviasky, E., ... & Abshire, P. (2013). An EMG biofeedback device for video game use in forearm physiotherapy. Paper presented at the 2013 IEEE SENSORS, Baltimore, MD. doi: 10.1109/ICSENS.2013.6688474

Crowther, R. G., Morken, C., & Pohlmann, J. M. (2015). Biomechanical comparison between traditional hula-hooping and Nintendo Wii hula-hooping. *Journal of Fitness Research, 4*(1), 3-12.

Damiano, D. L. (2009). Rehabilitative therapies in cerebral palsy: The good, the not as good, and the possible. *Journal of Child Neurology, 24*(9), 1200-1204. doi: 10.1177/0883073809337919

da Silva, F. F., de Souza, R. A., Dias, E. F., Silveira Jr, L., & Villaverde, A. B. (2015). Effects of feedback on activation of the quadriceps during weight-bearing tasks of the Wii. *Journal of Physical Therapy Science, 27*(6), 1701-1704. doi: 10.1589/jpts.27.1701

Dörrfuß, K., Bader, F., Wegener, R., Siemon, A., Schwake, J. U., Hofman, F., ... & Schmid, U. (2008). Video games can improve performance in sports: An empirical study with wii sports bowling. In: Seminar Human Computer Interaction. Retrieved January 19, 3027 from http://www.cogsys.wiai.uni-bamberg.de/teaching/ws0708/hci/practice/BowlingWii08.pdf.

Gennisson, J. L., Cornu, C., Catheline, S., Fink, M., & Portero, P. (2005). Human muscle hardness assessment during incremental isometric contraction using transient elastography. *Journal of Biomechanics, 38*(7), 1543-1550. doi: 10.1016/j.jbiomech.2004.07.013

Gilroy, S., Porteous, J., Charles, F., & Cavazza, M. (2012). *Exploring passive user interaction for adaptive narratives*. Paper presented at the Proceedings of the 2012 ACM international conference on Intelligent User Interfaces, Lisbon, Portugal. doi: 10.1145/2166966.2166990

Hermens, H. J., Freriks, B., Merletti, R., Hägg, G. G., Stegeman, D., Blok, J., Rau, G., & Disselhorst-Klug, C. (1999). SENIAM 8: European recommendations for surface electromyography, deliverable of the SENIAM project. Enschede, The Netherlands: Roessingh Research and Development.

Hong, J. S., Kim, J. H., Hong, J. H., & Chun, K. J. (2012). Electromyograph Analysis during Isokinetic Testing of Shoulder Joint in Elderly People. *Journal of Biomechanical Science and Engineering, 7*(4), 379-387. doi:10.1299/jbse.7.379

Lanningham-Foster, L., Jensen, T. B., Foster, R. C., Redmond, A. B., Walker, B. A., Heinz, D., & Levine, J. A. (2006). Energy expenditure of sedentary screen time compared with active screen time for children. *Pediatrics, 118*(6), e1831-e1835. doi: 10.1542/peds.2006-1087

Lategan, L., & Krüger, P. E. (2007). Effect of two different handgrip positions on elbow peak torque values. *South African Journal for Research in Sport, Physical Education & Recreation, 29*(2), 67-74. doi:10.4314/sajrs.v29i2.25969

Lehman, G. J., Buchan, D. D., Lundy, A., Myers, N., & Nalborczyk, A. (2004). Variations in muscle activation levels during traditional latissimus dorsi weight training exercises: An experimental study. *Dynamic Medicine, 3*(1), 4. doi: 10.1186/1476-5918-3-4

Li, C., Rusák, Z., Horváth, I., & Ji, L. (2014). Influence of complementing a robotic upper limb rehabilitation system with video games on the engagement of the participants: a study focusing on muscle activities. *International Journal of Rehabilitation Research, 37*(4), 334-342. doi:10.1097/mrr.0000000000000076

Lui, D. P. Y., Szeto, G. P. Y., & Jones, A. Y. M. (2011). Neck and upper limb muscle activity during electronic game playing in school children. *Hong Kong Physiotherapy Journal, 29*(2), 99-100. doi:10.1016/j.hkpj.2011.08.023

Martens, J., Figueiredo, P., & Daly, D. (2015). Electromyography in the four competitive swimming strokes: A systematic review. *Journal of Electromyography and Kinesiology, 25*(2), 273-291. doi:10.1016/j.jelekin.2014.12.003

Mathiassen, S. E., Winkel, J., & Hägg, G. M. (1995). Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies—a review. *Journal of Electromyography and Kinesiology, 5*(4), 197-226. doi:10.1016/1050-6411(94)00014-X

McGill, S. M. (2001). Low back stability: from formal description to issues for performance and rehabilitation. *Exercise and Sport Sciences Reviews, 29*(1), 26-31. doi:10.1097/00003677-200101000-00006

Mekler, E. D., Bopp, J. A., Tuch, A. N., & Opwis, K. (2014). *A systematic review of quantitative studies on the enjoyment of digital entertainment games*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada. doi:10.1145/2556288.2557078

Moreau, C. E., Green, B. N., Johnson, C. D., & Moreau, S. R. (2001). Isometric back extension endurance tests: A review of the literature. *Journal of Manipulative and Physiological Therapeutics, 24*(2), 110-122. doi:10.1067/mmt.2001.112563

Rab, G., Petuskey, K., & Bagley, A. (2002). A method for determination of upper extremity kinematics. *Gait & Posture, 15*(2), 113-119. doi:10.1016/S0966-6362(01)00155-2

Ravaja, N., Saari, T., Turpeinen, M., Laarni, J., Salminen, M., & Kivikangas, M. (2006). Spatial presence and emotions during video game playing: Does it matter with whom you play?. *Presence: Teleoperators and Virtual Environments, 15*(4), 381-392. doi:10.1162/pres.15.4.381

Rios, D. C., Gilbertson, T., McCoy, S. W., Price, R., Gutman, K., Miller, K. E. F., ... & Moritz, C. T. (2013). NeuroGame Therapy to improve wrist control in children with cerebral palsy: A case series. *Developmental Neurorehabilitation, 16*(6), 398-409. doi:10.3109/17518423.2013.766818

Witvliet C. V., Vrana S. R. (1995). Psychophysiological responses as indices of affective dimensions. *Psychophysiology, 32*(5), 436-43. doi: 10.1111/j.1469-8986.1995.tb02094.x

Wankel, L. M. (1993). The importance of enjoyment to adherence and psychological benefits from physical activity. *International Journal of Sport Psychology, 24*(2), 151-169.

Zaitsu K, Hayashida K, Kajiwara J, Matsuguma H, Higuchi S. (2014) Evaluation of the physiological and psychological effects of video game for sit to stand exercise. *Japanese Journal Of Physical Fitness And Sports Medicine, 63*(5), 469-73. doi:10.7600/jspfsm.63.469

Zannatha, J. M. I., Tamayo, A. J. M., Sánchez, Á. D. G., Delgado, J. E. L., Cheu, L. E. R., & Arévalo, W. A. S. (2013). Development of a system based on 3D vision, interactive virtual environments, ergonometric signals and a humanoid for stroke rehabilitation. *Computer Methods and Programs in Biomedicine, 112*(2), 239-249. doi: 10.1016/j.cmpb.2013.04.021

Zimmerli, L., Jacky, M., Lünenburger, L., Riener, R., & Bolliger, M. (2013). Increasing patient engagement during virtual reality-based motor rehabilitation. *Archives of Physical Medicine and Rehabilitation, 94*(9), 1737-1746. doi:10.1016/j.apmr.2013.01.029