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Original Article

The use of virtual reality in table tennis training: a comparison of selected muscle activation in upper limbs during strokes in virtual reality and normal environments

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Abstract

The objective of this study was to assess the level of agreement between muscle involvement in the upper limbs of table tennis players during training in virtual reality (VR) versus a normal training environment. The research was conducted on an intentionally selected sample of 8 female probands who actively compete in a table tennis league. We monitored the activity of four selected upper limb muscles (biceps brachii, extensor carpi ulnaris, flexor carpi radialis, and posterior deltoid) during two basic strokes (backhand and forehand topspin). The study assesses the overall muscle activation in two different environments: a regular training environment and VR. To obtain data during two basic strokes (backhand and forehand topspin), we utilized a device (Noraxon) that measures and evaluates muscle activation using surface electromyography posterior. For the VR training environment, we employed the Eleven Table Tennis program with the head-mounted display HTC Vive Pro Eye. On the other hand, the regular training environment involved the use of a Joola Table Tennis Buddy Pro robotic ball feeder. The results showed that the total muscle activation of the selected muscles varied significantly between the two environments (regular training versus VR). Specifically, for selected muscles there was a notably higher muscle load when playing in the regular environment compared to VR. Based on these findings, we recommend using the virtual environment for training only for beginners or for casual table tennis playing. For performance-level players, VR is not a suitable training tool in terms of muscle activation.

Keywords: **HMD, muscle activation, sEMG, table tennis, virtual reality**

Introduction

Virtual reality (VR) is a technology that simulates environments, situations, and circumstances. The environments can be fictional or real, and VR tries to provide the most realistic representation of the actual conditions. VR allows us to experience a wide range of scenarios by fully replacing perceptions of our environment. In essence, VR allows us to see another world and hear its sounds. Currently, we are at the origin of VR development, and companies are investing considerable resources in this technology anticipating future VR success. According to LaValle (2020), VR induces actions through targeted behavior with artificial sensory stimulation, often with the user having minimal awareness of the artificial intervention. In human studies, VR is considered a powerful tool owing to its ability to control presented stimuli including visual, audio, kinetic, and haptic stimuli (Li et al., 2017). This immersive experience draws users into the VR environment, allowing them to engage in various activities (Balkó et al., 2018). In sports, VR systems hold significant potential for skill training and have gained considerable interest. They offer practical and pedagogical advantages. However, concerns exist regarding negative transfer when practicing movement skills, particularly owing to a lack of haptic information (response) or stereoscopic display distortion. The "specificity of learning" theory suggests that VR may be ineffective or even detrimental if there are significant differences (e.g., perceptual deficits) between practice and actual task conditions. Nevertheless, the "structural learning" theory suggests that VR can still be a valuable training tool because learners can grasp the underlying structure of movement patterns (Harris et al., 2020). Currently, VR has become prevalent in various professional sectors including medicine (Satava & Jones, 1998), architecture (Davila Delgado et al., 2020), and pedagogy (Hamilton et al., 2021). It is also widely used in the sports environment, catering not only to professionals but also to amateurs (Kim & Ko, 2019; Kulpa et al., 2016; Neumann et al., 2018; Nor et al., 2020). The advantages of VR in sports are numerous, offering control over objects, virtual players, and the virtual world itself. VR is being utilized in sports simulations, such as in handball (Bideau et al., 2003) or rugby (Miles et al., 2013), where it replicates engagements between players. It is also applied in training of more complex movements, for example rowing (van Delden et al., 2020) or juggling (Kahlert et al., 2015; Lammfromm & Gopher, 2011), as well as in downhill skiing (Wu et al., 2019), football referee training (Gulec et al., 2019), and golf (Choi et al., 2018). Moreover, VR is used in home environments for various sports training, from running and cycling to skill-based games aimed at developing

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speed and endurance (Kulpa et al., 2016; Neumann et al., 2018). VR is also used to simulate penalty kicks, subjecting participants to psychological pressure through fictitious stimuli. This experience prepares athletes for real conditions, potentially leading to adaptive responses when faced with similar situations in the actual environment (Stinson & Bowman, 2014). Because table tennis requires a high level of coordination, reaction, and anticipation, there are already several VR games and simulators designed for this sport (e.g., Eleven Table Tennis, RacketFury, etc.). The manufacturers of virtual glasses and games themselves, in their promotional materials, promise a very realistic environment suitable for training players (*Eleven VR*, 2023). Within such VR games, players can select various types of shots using a ball feeder, allowing them to define in detail specific situations such as direction, rotation, and speed. The physics of these simulators is remarkably realistic, enabling players to compete against artificial intelligence or real opponents through online multiplayer matches.

The main purpose of our study is to determine the level of muscle activation during table tennis training under two different types of environments (regular and virtual) using surface electromyographic (sEMG) analysis of muscle activation. This method is widely used in the field of muscle activation because it is affordable and accurate, and it can be used both in laboratory and in field conditions. sEMG analysis has been employed in previous studies on muscle activation during sports performance (Balkó, 2016; De Luca, 1997; Hug, 2011; Konrad, 2005; Velé, 2016). By examining the kinesiological aspect of movement and the time descriptors of individual muscle activation during table tennis training, we aim to identify individual similarities and differences in the "internal technique", i.e., coordination aspects of specific movement skills. Kinesiological comparison of specific table tennis movements in real and virtual environments offers valuable insights that can make the preparation and training of table tennis players more effective. Our study seeks to complement existing research in this area, building on prior studies that utilized sEMG measurements to compare the movements of table tennis players (Haghighi et al., 2021; Kondrič et al., 2006; Le Mansec et al., 2018; Maheshwari et al., 2022; Tsai et al., 2010). Although there are many studies on the use of VR in table tennis (Bufton et al., 2014; Liu et al., 2020; Michalski et al., 2019; Oagaz et al., 2022), none have specifically explored the muscle involvement in VR and normal environments during table tennis training. Hence, our research aims to fill this gap and provide valuable insights into the agreement between muscle involvement in table tennis players during training in VR and normal environments.

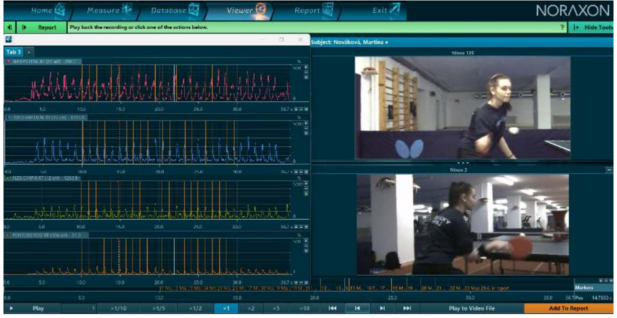
Materials and methods

Participants

The research group comprised 8 highly skilled female table tennis players, aged between 16 to 20 years, who actively competed in the top tier of Czech competition. These players were known for their attacking style and had no movement restrictions or injuries that could hinder their performance. Of note, a kinesiology analysis of the test subjects was not conducted in this study. The overall data sample was obtained through a purposeful selection process.

Procedure

The analysis focused on attacking strokes, namely the backhand and the forehand topspin, because they are some of the most challenging techniques in table tennis. These strokes are fundamental for every table tennis player. The monitored muscles were selected based on previous research investigating muscle activation in the upper limbs when playing table tennis and included the biceps brachii (BB), extensor carpi ulnaris (ECU), flexor carpi radialis (FCR), and deltoid posterior (DP) (Ozsu et al., 2014; Tsai et al., 2010). Before measuring the strokes, the maximum free contraction (MFC) of each muscle was measured to provide a reference for the subsequent measurements. Data collection for muscle activation involved the use of a device (Noraxon, MB 3.18, myoMUSCLE™) equipped with surface electromyography (sEMG) capabilities. This device allowed us to accurately measure and assess muscle activation during the backhand and forehand topspin strokes. For the VR training environment, we utilized the Eleven Table Tennis simulator equipped with a head-mounted display (HMD, VR glasses) HTC Vive Pro Eye and a wireless adapter. In contrast, for the normal training environment, we employed a Joola Table Tennis Buddy Pro robot (Figure 1) to serve the balls. The setup for the normal training environment was carefully arranged to mirror the conditions of the virtual environment, following the expert assessment of a competitive league player (Figure 2).



Play back the recording or click one of the actions below.

Subject: Nováková, Martina

Figure 1. Regular (normal) training environment

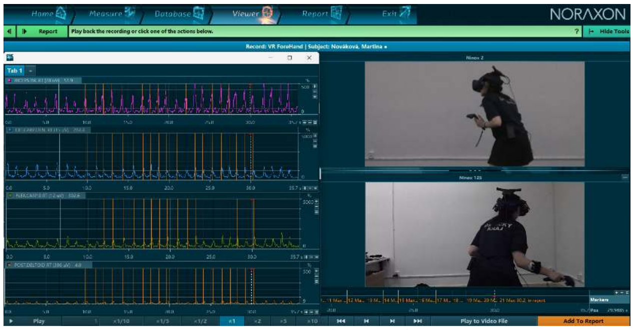


Figure 2. VR training environment

Data collection and analysis

The raw EMG signals underwent band-pass filtering (20–500 Hz) and were then whole-wave rectified using a linear envelope with a 10-ms window. For each muscle, 20 steady motion cycles (1 cycle = beat) were selected from the modified signal. The beginning of each cycle was determined as the point with the highest measured muscle effort during the stroke, corresponding to when the playing hand was directed towards the flying ball for striking. The final phase was characterized by the completion of the stroke and the return of the playing hand to the leverage position (i.e., the point just before the next stroke, when the developed force returns to the maximum again). To enable comparison between individual muscles, the timeline was normalized to a percentage value. Because the data did not follow a normal distribution (based on the Shapiro–Wilk test), we utilized non-parametric procedures for data analysis. Specifically, the resulting values of each muscle for one type of stroke were compared with the activity of the same muscle during VR training among the probands using the Wilcoxon test (Hendl, 2015).

Results

Table 1 presents the involvement values of individual muscles in both the normal environment and VR, along with a statistical analysis comparing the differences between the environments for two different types of basic strokes.

Table 1. Total muscle activation of selected muscles in virtual and real environments [% MFC]

Muscle	*Reality*	*M*	*SD*	*Min*	*Q1*	*Mdn*	*Q3*	*Max*	*p*	*CLES*
Backhand										
BB	Normal	21.79	9.22	5.70	14.56	21.69	28.93	35.30	**0.002**	0.64
	VR	17.25	7.85	4.24	12.87	16.14	23.19	30.07		
ECU	Normal	22.48	9.52	7.49	18.90	22.81	25.19	43.28	**0.002**	0.70
	VR	17.95	9.25	6.05	13.62	16.04	20.64	40.80		
FCR	Normal	30.60	36.23	4.61	12.40	19.55	25.89	129.7	0.054	0.59
	VR	23.83	26.45	7.61	10.91	13.69	15.85	95.95		
DP	Normal	26.62	10.86	13.77	18.16	23.70	31.78	48.21	**0.020**	0.50
	VR	20.31	7.87	9.88	13.35	19.70	26.19	34.75		
Forehand										
BB	Normal	19.84	5.53	9.83	1.40	22.94	23.88	25.99	**0.002**	0.81
	VR	12.70	5.03	4.13	8.66	13.24	16.04	21.30		
ECU	Normal	36.00	19.11	17.59	21.74	28.30	42.18	73.28	**0.002**	0.73
	VR	23.21	15.80	7.05	11.47	18.54	29.48	61.81		
FCR	Normal	30.54	20.89	7.63	16.84	23.66	35.83	76.25	**0.027**	0.69
	VR	19.58	14.46	5.26	8.14	19.27	20.61	53.09		
DP	Normal	29.81	12.82	17.38	21.35	24.05	33.81	59.52	**0.013**	0.81
	VR	17.62	6.69	7.31	14.22	17.74	21.78	28.69		

BB – m. biceps brachii, ECU – m. extensor carpi ulnaris, FCR – m. flexor carpi radialis, DP - m. deltoid posterior, M – mean, SD – standard deviation, Q1 – lower quartile, Q3 – upper quartile; CLES – Common Language Effect Size

In the backhand topspin, we found a significant difference in the total muscle activation of the BB muscles ($p \leq 0.01$), with the average level of total muscle activation being higher in the real environment compared to the virtual environment (difference between means: 4.54%). The same trend was observed for the ECU ($p \leq 0.01$, 4.53%) and FCR ($p \leq 0.01$, 6.77%), where total muscle involvement was higher in the normal real environment than in the virtual environment. However, we did not find significant differences in the DP muscle between the regular and VR environments ($p \geq 0.05$). Analyzing the muscles with the highest work during the backhand topspin (% MFC), we observed the greatest muscle involvement in FCR, followed by DP, ECU, and BB. This pattern applied to both types of environments (regular and VR). Although the level of muscle activation differed between environments, the muscles were loaded in a similar way in VR, but with a load that was several percent lower (Figure 3). When analyzing the forehand topspin, we arrived at similar conclusions: a higher muscle load occurred in a real environment compared to a virtual one (Figure 3). In this case, we found significant differences in all monitored muscles: BB ($p \leq 0.01$, 7.14%), FCU ($p \leq 0.01$, 12.79%), FCR ($p \leq 0.05$, 10.96%), and DP ($p \leq 0.05$, 12.19%). Similar to the backhand, we observed a similar trend in the forehand topspin, where the monitored muscles were involved to a similar degree in both the normal and VR environments. In both environments, the ECU muscle was most involved, followed by FCR, DP, and finally BB.

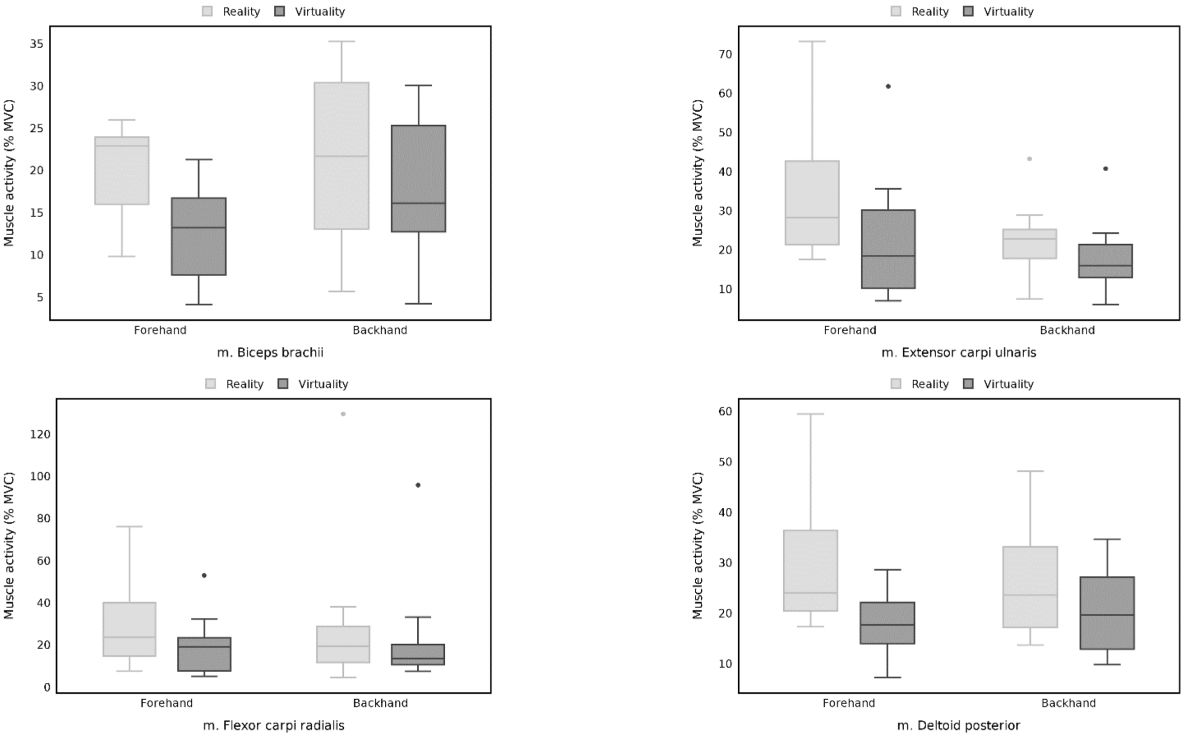


Figure 3. Total muscle activation of selected muscles in virtual and normal environments

Discussion

Based on the presented results, it is evident that the muscle activation of selected muscles during basic backhand and forehand topspin strokes differs between normal and virtual environments, with higher muscle involvement observed in the normal environment. We believe that the current form of VR is more suitable for novice players or entertainment purposes. However, it is crucial to closely monitor the advancements in VR technology, particularly in HMD displays and haptic feedback capabilities. We attribute the biggest difference in muscle activation to the absence of haptic feedback and the varying weights/centers of gravity of HMD controllers. Resolving these shortcomings in the future may potentially lead to identical muscle loads in both environments. For future research studies, we recommend choosing a different type of controller and a newer HMD. Le Noury et al. (2022) have highlighted that VR for sports is still in its early stages and lacks essential features for optimal use. One of these factors is the reality of the environment, which significantly impacts visuomotor reaction time. It is possible that the current unreality in VR may affect reaction times and muscle contractions during strikes (Hülsdünker & Mierau, 2021). Similarly, Rusdorf and Brunnett (2005) have compared VR and reality. They suggest that while VR can be considered real and useful for training beginners, it may not fully replicate the speed of the ball and the characteristics of the racket for experienced players.

Conversely, Michalski et al. (Michalski et al., 2019) reported positive findings in their research on the effects of transferring VR table tennis training to real-world table tennis performance. They observed a significant improvement in the measured probands who were complete beginners. Of note, these beginners found playing in the VR environment to be a natural and intuitive experience.

Based on our results, which disprove the notion that average muscle activation in VR is equivalent to the real environment, we recommend further research with a focus on improving the realism of VR. This includes enhancing the characteristics of the bat, the bounce of the ball, and the speed of the flying ball.

Conclusion

The results of our study clearly indicate a significant difference in the activity of the analyzed muscles in table tennis players during forehand and backhand topspin strokes in both regular and VR environments. Except for the m. flexor carpi radialis, none of the selected muscles show a higher strain when playing in VR (as shown in Table 1). However, for other muscles, there is a notable disparity in the total muscle load for topspin strokes between the two environments (Figure 3). Specifically, topspin strokes played in the normal environment demonstrate a considerably higher muscle load compared to strokes executed in VR. This discrepancy is likely attributed to the absence of haptic feedback in the VR setting. Although muscle activation during topspin strokes is higher in the real environment, it is important to note that our study does not definitively rule out the possibility of identical kinematic motion in both environments. To further explore this aspect, we recommend implementing a 3D motion analysis using inertial measurement units to ascertain whether the kinematics of the movement are indeed similar between the two settings. Based on our findings, we advise against high-performance players solely relying on a VR environment for the development of strength and cardio conditioning because VR currently lacks the ability to fully replicate the muscle load experienced in a real environment. However, a VR environment may hold potential benefits for novice table tennis players.

Conflicts of interest

We declare that we have no conflicts of interest.

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