Paralympics table tennis' forehand motion pattern: comparison of virtual reality and real task conditions

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Edna Azevedo Guimarães*
Paulo Daniel Sabino Carrara*
Thiago Toshi Teruya*
Jaqueline Freitas de Oliveira Neiva*
Talita Dias da Silva*
Carlos Bandeira de Mello Monteiro*
Luis Mochizuki*

*School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, SP, Brazil.

Abstract

The aim of this study was to compare sport specific para table tennis' forehand motion pattern during virtual reality and real task conditions. Nineteen Paralympics table tennis players performed the forehand stroke in real and virtual environments. One three-dimension accelerometer fixed on table tennis racket and on Wii remote control was used to record forehand kinematics data. Acceleration and jerk were the kinematic variables analyzed during the forehand. The forehand acceleration (H=3.9 p=0.04) and jerk ($F_{1.36}$=25.1 p<0.001) in real environment were significantly higher than in virtual environment in transverse direction. Thus, practice in virtual environment did not provide sufficient stimulus to Paralympics table tennis players to reproduce forehand motion patterns as in real environment. The practice in virtual environment may contribute, but not replace practice in the real environment for competitive Paralympics table tennis players.

Keywords: Exergames; Game mechanisms; Training simulation; Psychomotor performance.

Introduction

During the first decade of the XXI century, virtual reality (VR) rehabilitation programs based on videogames like Nintendo Wii® and Xbox 360 Kinect® have been used within multidisciplinary approaches to assist individuals with disabilities to improve their movements[1]. These videogames are known as exergames, engaging the participant by combining gaming and physical activity[2] and it is a novel tool for rehabilitation. Advantages of VR technology include the opportunity of providing extended practice in the patient's own home or community[3]; also the possibility to create tasks that can be controlled, programmed and modified according to user abilities, allowing them to interact in an environment that is potentially more motivating than traditional rehabilitation settings[4].

Furthermore, arm movements training in VR environments may be a valid approach for rehabilitation of patients with motor disorders[3,] because it is possible to encourage completion of rehabilitation exercises that may be considered less motivating due to repetition[5]. The engagement into VR condition increases exercise adherence and commitment to a rehabilitation program, and both (adherence and commitment) are important factors to improve the performance during exercises.

Due to the controllability of computer-generated conditions in VR, therapists can easily and precisely manipulate the target's speed and timing to adjust the game's challenge according to participant needs[6]. Some studies with Nintendo Wii®[7-9] provided a modest level of evidence to support using commercially available VR gaming systems for the treatment of different deficits. Therefore, clinicians can more precisely control movement constraints within VR (exercise duration, intensity, and environment), than in a real-world (RW) task[10] to create satisfactory conditions for the clinical treatment.

Training of sports-related skills is another fast emerging application of VR[11]. The use of VR as training to improve performance of para table tennis athletes is a promising possibility. Despite doubts about skill transferring from virtual to real environment in persons with physical disabilities[12], some specific factors may contribute for its use: 1) training without using a real table that takes too much space; 2) no need to catch the table tennis ball when it falls on the ground - particularly complicated for wheelchair users; 3) to practice with an avatar that enables to play at any time and place.

The use of VR environments to improve physical activity has been investigated with Nintendo Wii® sports: children with cystic fibrosis[13] and population with Parkinson's disease had shown improvement of motor and non-motor symptoms[14].

Other studies about VR and individuals with disabilities have shown interesting results[1, 10, 15-18] but barely have compared the differences between real and virtual environments on the same movement action. During walking tasks, the major findings suggest that virtual trajectories always exhibit some fundamental characteristics of real locomotion[19].

However, movements in VR were slower than in the RW, had longer deceleration times[20], and had higher duration[3] than in RW for the same task of reaching, grasping, transporting and releasing a ball. Although, one limitation to these gaming studies is tasks similarity in both conditions, or their ecological validity[21].

Traditionally, depending on each situation, distinct movement sensors are applied[22] to provide data about the kinematics of the movement. For table tennis, accuracy and precision of the end point reveals the way the racket hits the ball[23]. It is important for the table tennis coaches to examine the effect of VR in specific sport movements, gathering more information for evidence-based decisions about using VR for training movement in para table tennis players. Kinematic information about racket accelerations would be worthwhile for a better understanding of table tennis forehand movement developed by athletes with disabilities; considering that there are few kinematic approach studies on forehand and that interpretation of kinematic contributions is intuitively easy, especially for players and coaches[23].

Indeed, the lack of combined studies about para table tennis, motor behaviour and biomechanics in VR encourage us to research about it. Specifically, is the smoothness of the motion pattern of the forehand in table tennis para athletes the same in VR? The null hypothesis is that there are no differences between VR and RW motion patterns. The purpose of this study was to compare the acceleration (dynamics) and jerk (smoothness) of forehand motion pattern performed in table tennis by Paralympics athletes in real and virtual environment.

Methods

This study was approved by the University of São Paulo ethics committee, protocol number PP 13501130. Informed consent was obtained from the participants or from parents/guardians for those participants who were below eighteen years old.

Participants

Nineteen para table tennis players were included in the study (Mean=27.1; SD=12.7 years old), class two to eleven according to para table tennis classification code. Participants in class 2-5: ten wheelchair players; class 6-10: eight players with standing disabilities; and one player class eleven - intellectual disability. Was included in this study only the para table tennis athletes registered in the Brazilian Table Tennis Federation and had been playing as athletes at least for three years, evidenced by participation in official competitions, as shown in TABLE 1.

TABLE 1 - Participants' characteristics.

Participant	Gender	Age	Lesion	Disability*	Classes**	Experience years
1	F	19	Traumatic brain injury	Left Hemiplegia	7	6
2	M	41	Spinal cord injury (C7-T1)	Tetraplegia	3	8
3	M	36	Spinal cord injury (C6-C7)	Tetraplegia	2	9
4	M	25	Charcot Marie-Tooth Syndrome	Deficits in lower limbs	6	11
5	F	39	Poliomyelitis	Large deficits in lower limbs	4	5
6	M	20	Traumatic brain injury	Left Hemiplegia	8	4
7	M	14	Myelomeningocele	Large deficits in lower limbs	5	4
8	M	45	Spinal cord injury (T11- T12)	Paraplegia	5	15
9	M	15	Hypophosphatemic Rickets	Small deficits in lower limbs	10	9
10	F	25	Cervical Medulloblastoma	Motor incoordination	6	5
11	M	16	Congenital disease	Intellectual disability	11	4
12	M	25	Traumatic brain injury	Left Hemiplegia	6	5
13	M	24	Spinal cord injury (C5)	Tetraplegia	2	4
14	M	60	Congenital Anomaly	Absence of the forearms and left leg	6	20
15	M	23	Spinal cord injury (L2-L3)	Paraplegic	3	10
16	F	13	Myelomeningocele	Large deficit in lower limbs	5	3
17	M	31	Spinal cord injury (T1-C3)	Tetraplegia	3	3
18	M	26	Traumatic brain injury	Left Hemiplegia	6	3
19	M	16	Moyamoya disease with stroke	Left Hemiplegia	7	3

F = female gender; M = male gender; * all participants were right-handed; ** Wheelchair users (1-5), walkers (6-10), intellectual disability (11).

Procedure

Participants were required to hit a ball with a table tennis racket (RW) or to intercept a virtual ball with a Wii remote control (VR) by forehand drive movements as accurately and as fast as possible towards a secondary target (real or virtual table).

For RW, the racket, ball, table and net were approved by the International Table Tennis Federation. To avoid opponent interference, a throwing ball machine (Donic/Newgy Robot-Pong 2000) was used with a standardized frequency and intensity to all participants.

Each trial for RW condition lasted 30 seconds. Table tennis balls were launched by the throwing machine. Launch frequency was 1 Hz for the first half of the trial, and it was 1.5 Hz for the second half of the trial. These frequency adaptations were needed to make the tasks similar between environments. Players were free to choose the way to execute the forehand. The only constraint was to hit the ball at the opposite side of the table tennis.

For VR, players performed repeated forehand drives for 30 seconds, using Wii remote control, three meters away from a 52-inch monitor (Sony Bravia Full HD, Sony Inc.) connected to a Nintendo Wii® console with the game Wii Sport Resort - table tennis. It was required to hit the virtual ball at the opposite side of the virtual table tennis. The accelerometer was fixed on the handle (racket or Wii remote control) to measure the acceleration orthogonal to frontal face of the handle, parallel to longitudinal main handle axis, and parallel to transverse main axis of the handle.

Forehand drive frequency was similar to throwing ball machine frequency. The number of drives was counted previously and used to set the frequency of throwing ball machine. Service direction was random, according to the machine in RW and by the console in VR. For every participant, he/she first performed the drive on RW and then on VR. To avoid acute effect of RW practice, forehand drive at VR condition was performed at least 1 hour after the RW condition.

For kinematics, a 3D accelerometer (Triaxial Model, EMG system, Brazil) was affixed to the racket handle or to the Wii remote control, at the same height of the centre of the hand. This location was chosen to provide information about the end point of the kinematic chain of the upper limb responsible for the forehand drive. Racket and Wii remote were about 180 g and 210 g weight, respectively. Accelerometer weight was 10 g and data were sampled at 2 kHz. Handshake grip was the same for all participants in both apparatuses.

Kinematic variables

Kinematic variables were peak acceleration and peak jerk of the racket and the Wii remote control movement. Threshold for acceleration measure was five standard deviations in beginning until reaches zero. Raw acceleration signal was low pass filtered (4th order Butterworth filter, 100 Hz cut-off frequency) and demeaned to remove the offset. Then, jerk (the first derivative) was calculated from the filtered and demeaned acceleration signal. Acceleration and jerk time series were rectified (only the absolute values were considered) for the calculation of mean and standard deviation of the peak values. For each participant, it was considered for analysis five repetitions of the forehand drive for every condition.

Data analysis

Analysis of variance (ANOVA) was applied to verify the effect of condition (VR and RW) within acceleration and jerk peaks. When data was not normally distributed and its variance was not similar between conditions, Kruskal-Wallis test was ran; on the other hand, when both conditions were accepted, one-way ANOVA and post hoc Tukey HSD test were applied. Matlab (R2010a, MathWorks) routines were run for data processing. Statistical significance level was set at 5%. Power analysis was performed with Cohen d effect size (ES), and ES interpreted as <0,1 trivial, 0,1-0,24 small, 0,25-0,40 medium and >0,4 large[24].

Results

Mean and standard deviation of acceleration peak at the two conditions are presented in FIGURE 1. For orthogonal direction ($F_{1.36}$=0.2 p=0.29, power: 0.06; ES<0.01; RW: 0.98±0.25 g; VR: 1.05±0.18 g) and longitudinal ($F_{1.36}$=0.07 p=0.79, power: 0.04; ES<0.01; RW: 0.86±0.37 g; VR: 0.86±0.27 g) directions, there was no effect of condition on acceleration peak. For transverse direction, condition affected the acceleration peak ($F_{1.36}$=25.1 p<0.001, power: 0.99, ES: 0.65; RW: 0.99±0.14 g; VR: 0.70±0.20 g). Tukey test showed that the highest acceleration peak occurred in RW practice, with large ES.

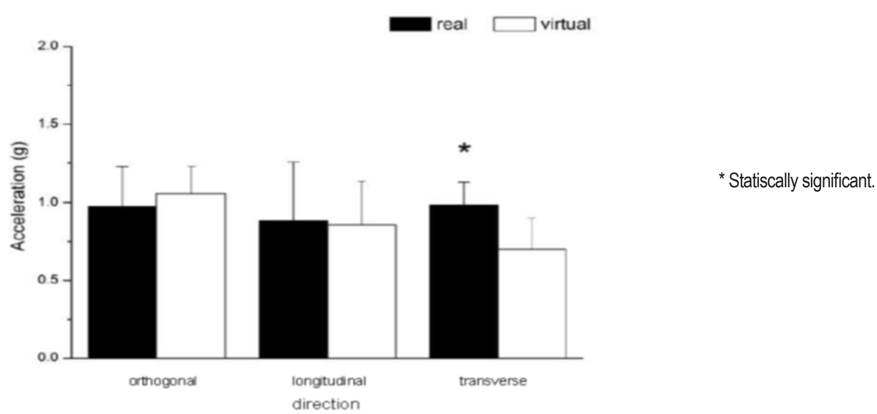
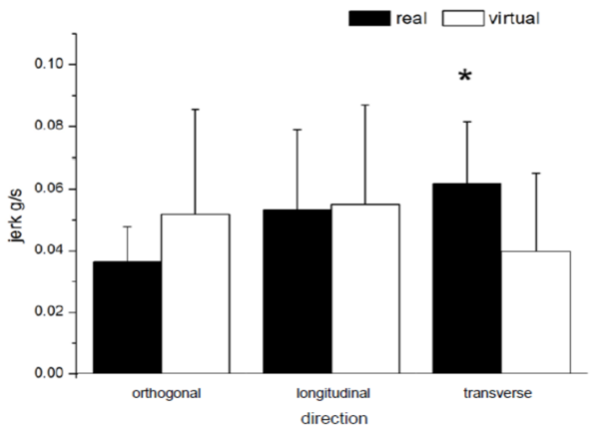


FIGURE 1 - Mean and standard deviation of the acceleration at the two conditions and three directions.

Mean and standard deviation of jerk peak at the two conditions are presented in FIGURE 2. ANOVA and Kruskal-Wallis test were used to identify condition effect (RW and VR) at the peak jerk of racket movement. There was no condition effect at the jerk peak neither for orthogonal direction (H=1.2, p=0.26; RW: 0.04±0.01 g/s; VR: 0.05±0.03 g/s), nor for longitudinal direction (H=0.1, p=0.73; RW: 0.05±0.03 g/s; VR: 0.05±0.03 g/s). Type of practice influenced peak jerk on transverse direction ($F_{1.36}$=8.7, p=0.005, power: 0.78; ES:0.44; RW: 0.06±0.02 g/s; VR: 0.04±0.03 g/s). Tukey test showed the highest peak jerk occurred in the RW practice, with large ES.



* Statiscally significant.

FIGURE 2 - Mean and standard deviation of jerk at the two conditions and three directions.

Discussion

The aim of this study was to compare forehand acceleration and jerk, performed in the RW and VR condition. Both acceleration and jerk peaks were lower for the VR condition. Moreover, the kinematics in the transverse direction was different, with strong power and large effect size of our sample. These results suggest that para table tennis players do not have the same forehand motion pattern in RW and VR conditions.

The highest transverse acceleration peak occurred when participants hit the ball against the table in RW condition. This takes place because the ball movement in VR elicits longer movement duration and lower peak velocity[25]. The expert table tennis players keep their eyes on the ball at the beginning of the trajectory and coordinate the strike, predicting the ball trajectory and coordinating their motion to hit the ball[25].

In VR, the ball trajectory can also be successfully predicted in order to hit a virtual ball correctly[26]. Thus, visual and spatial strategies are applied, based on predictions of ball's speed. Conversely, there are differences whether the reaching movement is performed in RW or VR, because in VR the participants maintain sight at the TV (not glancing to the target). Differences in movements in the two environments may be explained by the absence of haptic feedback from VR[3], or due to an uncertainty about object location in VR[20].

Some constraints must be considered in order to analyze the higher acceleration and jerk in RW forehand performance. First, the player must ensure that the racket contacts the ball. Second, the racket has to travel with a high velocity at the moment of ball/racket contact to impact a large impulse onto the ball. Finally, the bat must be travelling in a precisely controlled direction at the moment of contact to push the ball to the target[27]. These constraints are not provided in VR condition due to real ball absence, which could imply why differences were observed in the results presented. These factors causing uncertainty about hitting the virtual ball may have influenced the motion pattern, comparing RW and VR environments.

For RW, the ball striking feeds effort perception. There is a direct relation between ball mass and hand force increase to counteract the interaction force[28]. Thus, hitting the ball harder requires increased hand force. In VR, effort perception is reduced due to absence of contact force. Less information being provided during striking the virtual ball may explain the lower acceleration in VR, aiming to control forehand movement. table tennis players, in the RW, decelerate movement at ball strike to increase accuracy[29], while that using higher arm velocities were more likely to miss the target[30]. Therefore, participants reduced the acceleration and jerk in the VR to hit the virtual table, due to lack of sensorial information about how to hit the ball.

Additional characteristics of VR (e.g., insufficient depth perception, haptic feedback and arbitrary association between vision and action) bring some limitations that may lead to different performances from those in RW[3, 31] as found in the present study, lower acceleration and jerk in VR.

In RW, players must select an appropriate trajectory for the racket based on information available early in ball flight[30]. As closer the ball is to the player when movement was initiated, as more force is applied during the stroke[27]. The absence of depth perception in 2D virtual condition may misjudge participant's knowledge about target location, slowing down the movement, pointing the importance of depth perception in VR for motor control[6]. Another explanation involves the type of haptic feedback provided to the player[3, 31]. The main interaction studied in the literature was ball / bat interaction. The difference in jerk found in the present study occurred only in the transverse direction, or the direction against the ball is hit. Thus, such differences would not be expected in other directions, as it would mean differences in the whole forehand action.

A player can control his hand movement by adjusting the muscle contraction level, as well as arm posture[28], which can influence forehand techniques. An example is distinctive movement acceleration to hitting the ball at an adequate angle, which is absent when playing the virtual ball. Purposeful movements under visual control require the transformation from a desired trajectory into muscle activation patterns. Central nervous system accomplishes this transformation under a great variation of visual or biomechanical circumstances[32].

Different mechanical features of racket handle (weight, size and air resistance) compared to Wii remote control might be considered, as players move their hands with more acceleration under higher resistance conditions[28]. Moreover, to avoid such differences between environments, relevant haptic feedback is necessary[3], indicating virtual ball/bat contact. To improve the feeling of VR immersion, exergame remote control needs to have similar characteristics to the racket, as a haptic signal of virtual bat hitting virtual ball.

The slighter number of extrinsic factors found in a task realized in VR lead to the assumption that the same task executed in the RW is more complex. A cortical analysis comparing tasks in different environments verified that the attention and neural activity were greater in RW than in VR[33]. Furthermore, latency also reduces the feeling of immersion into the game, contributing negatively to training experience[11]. The practice of VR table tennis within these characteristics seems to be not suitable for specific training requirements of Paralympics players.

Considering sportive aiming, it is desirable to accelerate the racket and hit the ball as fast as the player can, to succeed over an opponent. It seems advantageous for table tennis players to be able to accelerate the racket within less time in forceful shots, because a limited time is usually allowed for them to execute a stroke in table tennis[23]. In the present study the Paralympics players did not accelerate the forehand drive in VR as much as they did in RW. Based on the present study, the null hypothesis that there are not differences between VR and RW motion patterns was rejected.

The current study has limitations that could have influenced the results. First, despite data fully representing the ability of the evaluated group, lack of familiarity with VR could contributed to the observed effect in the transverse direction. The second issue is in relation to the participants diagnostic and classification, as different impairment and classifications types were included in the group, as standing and wheelchair participants, these could have affected forehand movements.

In conclusion, there is a growing interest in using virtual games in the context of adapted sports. Clearly, the utility of a VR for sports training is dependent on the capabilities of the available technology component[11]. In this study, the practice in VR was very similar to RW, but does not seem to be valid to reproduce forehand characteristics of RW competitive players. The motion pattern of forehand was modified in VR on the most important aspect, to return the ball as fast as possible to suppress the opponent, characterized by the action in the transverse direction. Thus, VR recommendation for competitive athletes is limited to training, but not as a tool for forehand technical improvement.

Motion pattern was different between

environments, possibly due to VR characteristics, as absence of ball mass, effort perception and depth perception. To improve virtual table tennis functional fidelity, it is suggested the improvement of haptic signal of virtual ball on virtual racket, and considered the development of new gaming technologies. More studies are required to reinforce these findings, also at the same time as the exergames are improved. Nonetheless, validation studies are required to analyze the similarity of athlete's behaviour in RW and VR and to confirm that training effectiveness is not affected[11].

Conflict of interest

None of the authors report any conflict of interests. All authors were responsible for the content and writing of this article.

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Resumo

Padrão de movimento do forehand no tênis de mesa paraolímpico: comparação entre realidade virtual econdições de tarefa real.

O objetivo deste estudo foi comparar o padrão de movimento de forehand do tênis de mesa durante a realidade virtual e as condições de tarefa real. Dezenove tenistas de mesa paraolímpicos realizaram o forehand em ambientes reais e virtuais. Um acelerômetro tridimensional fixado na raquete de tênis de mesa e no controle remoto do Wii foi usado para registrar dados cinemáticos de forehand. Aceleração e arrancada foram as variáveis cinemáticas analisadas durante o forehand. A aceleração de forehand (H=3,9 p=0,04) e a arrancada ($F_{1,36}$=25,1 p<0,001) no ambiente real foram significativamente maiores do que no ambiente virtual na direção transversal. Assim, a prática em ambiente virtual não forneceu estímulo suficiente para que os mesa-tenistas paralímpicos reproduzissem padrões de movimento de forehand como no ambiente real. A prática em ambiente virtual pode contribuir, mas não substituir a prática em ambiente real para atletas mesa-tenistas paralímpicos.

Palavras-chave: Exergames; Mecanismos de jogo; Simulação de treinamento; Desempenho psicomotor.

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Address
Paulo Carrara
School of Arts, Sciences and Humanities
University of São Paulo
Av. Arlindo Bettio, 1000
03828-000 - São Paulo - SP - Brazil
Email: paulocarrara@usp.br

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