Effects of reintroducing haptic feedback to virtual-reality systems on movement profiles when reaching to virtual targets

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ABSTRACT

Virtual Reality (VR) has been shown to have significant impacts on the efficacy of rehabilitation, improving a patient's motivation and participation, as well as improving scores in functional assessments when used to enhance traditional therapy. However, movements in VR have been demonstrated to have significant differences in movement profiles whilst performing simple reaching tasks compared to their real counterparts. The lack of tactile perception in VR systems is often attributed to be one of the causes of these differences. Therefore, to investigate the degree to which the lack of haptic feedback impacts movement profiles in VR, we have reintroduced the sense of touch through vibration motors on the fingertips. Participants were required to reach to virtual targets, both with and without haptic feedback. Their movements were quantified using motion capture, and the virtual targets were rendered using the Oculus Rift. The motions to both targets were compared using a number of measures to characterize the velocity profiles. Preliminary results suggest that the reintroduction of haptic feedback improves performance based indicators in virtual reaching tasks, such as the time to complete a reach, and the stability of the reaching hand whilst touching the virtual target.

1. INTRODUCTION

Reaching is a fundamental action performed in everyday life, and the ability to do so is often diminished in the elderly, or in persons with neurological disorders, making upper limb rehabilitation of particular importance. Virtual Reality has been demonstrated to be an effective tool in such rehabilitation, with Henderson (2007) and Rand (2014) finding that VR based exercises were superior to their traditional counterparts.

Particularly during stance, reaching movements involve a complex coordination between movement and balance, performed by the central nervous system (CNS) (Hua 2013). The muscular activation and recruitment patterns of reaching movements in reality are well understood (Leonard 2009), though movements in VR have been demonstrated to not follow these same rules. The kinematic differences in VR movements have been found to negatively impact performance based indicators, such as accuracy and target acquisition time (Chen 2014). Multiple studies have quantified these differences, with Samini (2015) demonstrating that there exists biomechanical differences in the activation of the shoulder in VR reaching strategies, and Just et al. (2016) finding significantly higher pelvic velocity in motion capture data, indicative of a higher degree of postural instability. These findings suggest that VR seems to affect some elements in the feedforward control systems employed in reaching movements.

The differences found between VR and non-VR movements have often been attributed to a number of different factors, including display latency, visual inaccuracies, and lack of haptic feedback (Oculus VR, 2016). Haptic feedback in the form of placing physical objects at the same position as their virtual counterparts has been shown to slightly improve grip aperture and orientation (Cuijpers 2008), however, this approach is task specific, and does not allow for generic feedback to be provided for any virtual object. Therefore, we have integrated into our virtual reality set-up a vibration motor on the end of the right index finger to simulate the somatosensory response of reaching to physical objects.

This study aims to investigate the assumption that the lack of haptic feedback in VR systems contributes to the previously found differences in movement patterns, by providing a proof of concept trial on healthy participants, which may in turn be utilised to normalise VR reaching tasks in rehabilitation exercises.

Proc. 11th Intl Conf. Disability, Virtual Reality & Associated Technologies
Los Angeles, California, USA, 20–22 Sept. 2016

2. METHOD

2.1 VR System Setup

The movements of participants were recorded using an XSENS MVN BIOMECH inertial motion capture suit, consisting of 17 microelectromechanical (MEMs) sensors placed on the body. The suit captures movements at 240Hz, and streams to the associated MVN Studio Pro software, where the sensor data is combined to animate a 23 segment kinematic model of the human body, with a latency of 20ms. The model data is then streamed as a collection of quaternion rotations into the Unity-4 game engine to control an avatar and mimic the movements of the user.

The Oculus Rift HMD is then used to provide an immersive visual projection of the virtual environment to the user, displaying the rendered scene from the position of the in-game model's head. The rotational and positional data from the HMD is used to control the direction orientation of the user's view.

Combining these two systems allows the user to move and look around the virtual environment; looking down, the user is able to see their virtual avatar's body, mimicking their real-life movements.

A simple circuit utilising an Arduino microcontroller and a small vibration motor was created to simulate the haptic feedback for the system. The vibration motor, measuring 10mm x 3.4mm and weighing 5g, was attached to the end of the user's index finger. Program code written in C# was created to activate the vibrational motor whenever a virtual collision event was detected, which occurred whenever the user touched a virtual object. The amount of force exerted on the virtual object by the virtual finger was calculated, and used to vary the PWM output to control the vibration motor.

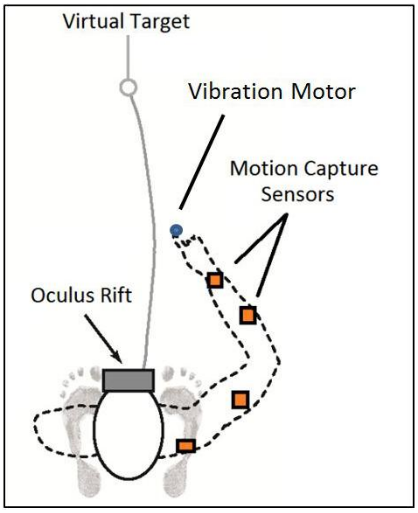

Figure 1. *Reaching to virtual target.*

This allows the user to experience variable haptic feedback when touching a virtual object; lightly grazing the object will give a light buzz, and jabbing an object with force will give a hard buzzing sensation.

2.2 Virtual Scene Setup

A simple scene was created in the Unity-4 game engine for the reaching task. The target was created to be a relatively complex polygonal object, which, combined with differential lighting techniques, has been shown to improve reaching performance in VR (Powell 2016).

The target was chosen to act in a number of different ways when touched in the virtual environment:

- Moves on a hinge joint to give visual feedback of the user's physical interaction with the object.
- Changes colour to indicate that it has been touched to give the user feedback that they have completed the task.
- A variable buzz is given to the end of the user's finger to simulate haptic feedback.

2.3 Procedure

Two healthy male right-handed participants (aged 20-25) were asked to reach to the virtual target in a standing position with a pistol grip. The pistol grip was chosen because it allows for the position of the end of the finger to be extrapolated from wrist angle and position without finger-level motion tracking. The target was initially calibrated to be positioned at 1.3 times the length of the participant's reach when feet are flat on the floor. The participants repeatedly reached for the target with their right hand (with the vibration motor attached to the index finger), held their index finger against the target for 5 seconds, retracted their hands to their chest, and held that position for 5 seconds. When haptics were enabled, the vibration motor buzzed in accordance to the level of force measured between the avatar's finger and the virtual target when touching.

The participants repeated this movement 30 times for each of 4 sessions (the initial 10 reaches of each session were removed to allow participants to become accustomed to the virtual environment). Each session was completed entirely with either the vibration motor enabled or disabled, with each participant completing 2 sessions of each. The first participant completed the session with haptics enabled, switching for each subsequent session, and the opposite for the second participant.

2.4 Quantifying the Data

In order to compare the results, a number of metrics were extracted from the motion capture data for each reaching movement, the means of which are presented here. The start point, maximum velocity magnitude achieved (Vmax), and the end point are used to construct an equivalent perfect reach, from which oscillatory movements and error are calculated. The velocity magnitude of reaching motions all exhibit a similar basic shape; a period of acceleration (activation) towards the maximum velocity, then a period of deceleration (settling) towards the target (see Figure 2). The periods of acceleration and deceleration should ideally be equivalent in length.

The relevant metrics extracted from the reach profiles for this study were as follows:

- *VMax.* The maximum velocity magnitude achieved.
- *ActGrad.* The gradient of the acceleration phase; how quickly the maximum velocity was achieved.
- *Time to Target.* The time taken to reach the target.
- *Symmetry Ratio.* The ratio between the duration of the acceleration and deceleration phases.
- *Settle MSE.* The amount of variability compared to the perfect reconstruction in the settling segment.
- *Holding MSE.* The amount of variation while holding the target position for 5 seconds.

The Settle MSE and Time to Target allow an effective characterisation of the difficulty a user experiences in acquiring the target, with virtual reaches exhibiting four times the variability, and two times the duration of their real counterpart reaches (Just 2016).

Table 1. *Participant #1 Results.*

Metric	Haptic Feedback Status	
	Enabled	***Disabled***
Vmax	0.995	0.917
ActGrad	0.019	0.018
Time to Target	1.675s	2.03s
Symmetry Ratio	0.355	0.310
Settle MSE	0.068	0.05
Hold MSE	0.0018	0.0028

Table 2. *Participant #2 Results.*

Metric	Haptic Feedback Status	
	Enabled	***Disabled***
Vmax	1.19	1.13
ActGrad	0.027	0.023
Time to Target	1.56s	1.80s
Symmetry Ratio	0.344	0.340
Settle MSE	0.053	0.046
Hold MSE	0.0094	0.015

3. RESULTS & DISCUSSION

As with previous studies (Just 2016), each participant exhibited a different base movement model, however comparison of haptic and non-haptic metrics displays a consistent impact of the introduction of haptic feedback.

The symmetry ratio, Vmax and ActGrad metrics all remained relatively unchanged by the introduction of haptic feedback. These metrics characterise the acceleration phase of the movement, and would suggest that this change does not significantly impact the initial activation of the reaching movement.

The deceleration phase of the movement profile, particularly the target acquisition, appeared to be improved when haptic feedback was enabled. The Time to Target was reduced on average by 14%, which confirms that participants were able to more quickly and accurately acquire the target with haptic feedback compared to visual feedback only. The Hold MSE was also markedly improved, with a 35% reduction in variability whilst holding the target position. This metric characterises the amount of instability, or 'hand waving', typical of haptic-less

VR systems. The large reduction in Hold MSE may be attributed to a 'light touch' sensory cue provided by the vibration motor, which has previously been demonstrated to improve balance even without providing mechanical support (Rabin 2013).

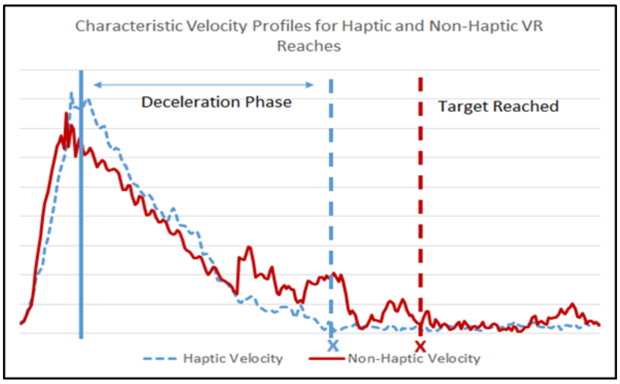

Figure 2. *Velocity profiles of characteristic results, X marks where the target was reached.*

4. CONCLUSION

These preliminary results demonstrate that the introduction of a replacement haptic feedback input improves performance based indicators in VR, such as the time to acquire a target. The main impact of introducing this feedback appears to affect the target acquisition phase of the reaching motion, as well as providing improved stability while holding at the virtual target.

Other facets of reaching profiles, which differ between VR and non-VR reaches, remain relatively unchanged, suggesting that haptic feedback is not likely to be the sole cause of these differences, though it does present a marked improvement on performance in VR. This proof of concept work provides promising results indicating that reaching exercises in VR may be made to more resemble their real counterparts by introducing simple haptic feedback. Further work is required to determine the impacts of such a system on a larger group, as well as the impact on the efficacy of motor rehabilitation.

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