Can visual stimulus induce proprioceptive drift in the upper arm using virtual reality?

D Willis, V Powell, B Stevens, W Powell

School of Creative Technologies, University of Portsmouth
Winston Churchill Avenue, Portsmouth, UK

{*dion.willis*, *vaughan.powell*, *brett.stevens*, *wendy.powell*}*@port.ac.uk*

www.port.ac.uk

ABSTRACT

Sustained isometric contractions (SIC), such as holding an arm stationary in a space, are often used in upper limb rehabilitation exercises, particularly where it is important to protect the joints and tendons or to reduce patient fatigue. However, visual cues within a virtual environment may have an unanticipated effect on the ability to maintain SIC. This study investigated the influence of background motion within a virtual environment on the ability to maintain a fixed position during an upper limb task. It was found that introducing directional movement had a significant differential effect on the ability to maintain SIC.

1. INTRODUCTION

Dynamic arm movements are commonly used in physical therapy to strengthen the arm and increase mobility after stroke, injury or amputation (Atkins & Robert III, 2012; Duncan et al., 2005). In recent years these rehabilitation practices have been coupled with virtual reality due to the tasks being repetitive and intensive, this is sometimes referred to as gamification (Burke et al., 2009). 'Gamification' has shown to be effective making long-term rehabilitation enjoyable and sustainable. Although dynamic movements have shown to be very beneficial for increasing mobility and range, these movements are sometimes too demanding/strenuous for patients suffering from chronic regional pain syndrome (CRPS-1), phantom limb pain (PLP), or post-stroke. (Moseley, 2006). Sustained isometric contractions (SIC) have been shown to provide equivalent strength development but also provide protection to the joints, tendons and muscles while remaining less strenuous for the patient. (Myers, Toonstra, Smith, Padgett, & Uhl, 2015). Similar to dynamic exercises, SIC rehabilitation is generally repetitive and intensive (Burke et al., 2009). When these rehabilitation techniques are placed into a virtual reality setting there may be unintentional repercussions on proprioception. For example, we know the appearance of objects in the virtual reality can influence the time it takes to reach for an object in upper limb tasks, (V. Powell & Powell, 2014) but there is little information about how movement in a virtual environment (VE) may affect upper limb proprioception and movement. Optic flow has been shown to influence the perception of self-motion during walking (W. Powell, Hand, Stevens, & Simmonds, 2006), but little is known about its effects on upper limb tasks. These side-effects of VR design (intentional or unintentional) could be detrimental to rehabilitation. This is especially true for SIC as the duration of the action is much longer than the stages of a dynamic movement. In order to create enjoyable and sustainable virtual rehabilitation for people with diminished upper arm range of movement, it is important to understand how movement in VE can influence the visuomotor system.

Early work into visuomotor controls was pioneered by Aglioti and Bridgeman (Aglioti, DeSouza, & Goodale, 1995; Bridgeman, Kirch, & Sperling, 1981; Goodale & Milner, 1992; Milner & Goodale, 1995). Increasing understanding of how visual input has an effect on how we perceive, plan and execute actions. One of the main conclusions of this early work was the "perception – action model", which suggests that vision and action are split into two different and distinct neural activities.

- *One that sub serves perceptual judgements (planning)*
- *Another that mediates visually controlled action (on-line control)*

This opened many debates as to whether optical stimulus/illusions had an effect on just the planning of an action, the action itself or both or neither. The evidence shows visual stimulus (perceived movement) having an effect on planning and initial acceleration and there is less evidence of it affecting the on-line control of the movement/reach or grasp (Carey, 2001; Franz, 2001; Glover, 2002; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Although these results are reinforced by multiple different tests regarding reaching and grasping, these results have been challenged in various ways. Bruno (2001) has stated that tasks that emphasise observer – relative reference frames may contradict the notion that the two systems are completely disassociated with each other. Observer – related reference frames refers to the adjustments made throughout a movement and the feedback loop from different reference points. The objective of this study was to investigate whether visual motion in a virtual environment affects action (SIC) in the upper arm.

2. METHODOLOGY

2.1 Hypothesis

"Movement of the background of a virtual environment will influence the ability to hold a static position during SIC". The independent variables were the direction of motion of the virtual environment background, and the visual appearance of the background environment. The dependent variable was the change in hand position (mm) whilst attempting to maintain SIC.

2.2 Design

An application was created in Unity (5.3.4f1, 64-bit) to track hand movements using a LEAP motion hand tracking device. The application consisted of a digital hand model, a reference object and different backgrounds that would move either left or right. The background moved at a constant rate of acceleration (0.02 m/s^2) through the trial, starting at 0 m/sec and ending at a velocity of 1.25 m/sec. This was the highest speed used in a pilot that did not cause discomfort for the duration of the trial. Participants were told to place their virtual hand inside a reference object and keep their arm and hand as still as possible throughout the trials. Once the application started the reference object disappeared. In order to obscure the primary goal of the task, a secondary task was implemented for the participants to perform. The participants were informed that bubbles would be floating down from the top of the view, terminating on the virtual hand. Their task was to press a button on a controller with their non-dominant hand if they 'felt' the bubble on their physical hand and to keep their hand as still as possible. In reality, the trajectory of the bubbles was actually linked to the hand position, so that if there was any unintentional drift of the hand, the bubble would still intersect with the virtual hand. Each trial lasted 30 seconds with a break of 30 seconds after every two trials in order to limit fatigue (additional breaks were allowed if the participant requested them). During these breaks, the investigator assessed for any signs of discomfort. Overall the participants performed 8 trials consisting of 3 backgrounds and 3 different movement patterns [Table 1]. Hand (X, Y, Z) and bubble (Y) position, button presses (number of times bubble was 'felt') and speed of the background motion were all recorded at 50 Hz to a text file.

Table 1. *List of conditions used: The presentation of the patterns and directions were fully counterbalanced with non-moving control conditions at the start and finish.*

Control (solid grey)	Pattern 1	Pattern 2
No-movement	No-movement	No-movement
N/A	Left	Left
N/A	Right	Right

2.3 Participants

A total of 12 participants were used (9 males, 3 females), with an age ranging from 26-57 (M= 37, SD 9.54). 11 participants were right hand and 1 person was Left handed. Volunteers were obtained from members of staff and students at the University of Portsmouth. The exclusion criteria for this study was: Severe visual impairments, shoulder injuries or restrictions, diminished proprioceptive awareness [e.g. Parkinson's, dyspraxia, etc.], people with visual field epilepsy and those with attention deficit hyperactivity disorder (ADHD), attention deficit disorder (ADD).

2.4 User interface

The user interface consisted of one of three backgrounds; blank [grey], Marbled and Pebbles. These were chosen due to the irregularity of the surface. This meant the background would be able to cycle, seamlessly multiple times across the field of view. These backgrounds did not have any highlighted area that would distract the user.

2.5 Equipment

A Leap Motion Controller was used to track hand movement at 50 frames per second. For this study, it was important to imbue a sense of embodiment onto the arm because the user needs to have a sense of ownership with the arm if they are to be immersed in the VE (Kilteni, Groten, & Slater, 2012). To further this sense of embodiment different skin tones were selectable by the users (3 male and 3 female hands all constituting 3 different skin tones) a fully rigged and animated arm was also used.

In order to fully immerse participants in the virtual environment and occlude the view of their own body, An Oculus Rift DK2 HMD was used, with drivers set to version 1.7 SDK 0.6.0.1, allowing extended monitor functionality. A 1920x1080p resolution with highest output settings was used. The application was created with Unity 5.3.4f1 (64-bit). The HMD output was set in the software as an extended monitor. This allowed the stereoscopic display to be retained without movement tracking. The reason head tracking needed to be disabled was because pitch and yaw have been shown to change the perception of speed in virtual reality (Li, Adelstein, & Ellis, 2009). Open broadcast software was then used to mirror the oculus onto an external screen to allow the investigators to monitor the participant view throughout the study. Participants were seated at a desk, and the height of the chair adjusted such that the arm was in a low fatigue position (45° elevation in the sagittal plane θ =0) (Wiker, Chaffin, & Langolf, 1990).

3. FINDINGS

The dependent variable was ‘overall hand drift’ (mm). Overall hand drift relates to the movement in the X-axis from the initial position (Final X position of the hand [30 seconds] minus Initial position [0 seconds]). Overall drift included both magnitude and direction. Quantitative data analysis was carried out using IBM SPSS v22.

A repeated-measures 2-way ANOVA (pattern x direction) demonstrated no significant effect for pattern type [$F_{(1, 11)}$ = .00, p = .99] on overall hand drift. Since the pattern did not have a significant effect on overall hand drift, the pattern data was collapsed (N=24) for the subsequent analysis and testing.

Table 2. *Mean and standard deviation of the collapsed data showing overall drift (mm) from initial position.*

	Right	**Left**	**No Movement**	**Control**
Mean	0.47	-5.47	-3.52	-4.77
Standard deviation	7.68	9.52	5.4	5.72

Following collapsing the data, a further repeated measures ANOVA was conducted, Mauchly’s Test of Sphericity indicated that the assumption of sphericity had not been violated, ($\chi^2(5)$ = 9.60, *p* = .0.88). There was a significant effect of movement type on overall drift ($F_{(3, 69)}$ = 5.28, p < 0.01).

A Shapiro-Wilk’s test (p> .05) confirmed that the overall drift results were approximately normally distributed, therefore, posthoc paired T-Tests were performed on the data.

There was a significant difference in the overall drift for Right directional movement (M=0.5, SD=7.7) and control (M= -4.8, SD=5.7) conditions; t (23) =-3.185, p < .01. Right direction and no movement (M=-3.52, SD=5.4) conditions; t (23) =-2.59, p = 0.016. Right direction and Left (M= -5.5, SD=9.52) conditions; t (23) =-2.9, p < .01, However, there was no significant difference in drift between left directional movement and control.

4. DISCUSSION

Overall hand drift generally moved leftward, even in the absence of a moving visual stimulus. As the population of the sample was predominantly right-hand, this leftward trend means their hand was travelling towards medial plane (centreline). This trend could be attributed to fatigue in the arm. This was not unexpected as the arm is horizontally flexed with the forearm pronated (Honan, Jacobson, Tal, & Rempel, 1996). However, presenting a rightward direction to the background motion induced a counteraction to this leftward trend either making the hand more still or reversing the direction of the drift against the leftward trend towards the medial plane. This finding suggests that a background moving laterally to the medial plane might be able to counteract the effects of fatigue in the upper arm. This could be beneficial for rehabilitation programs as this may mean patients could hold fixed positions for longer periods of time. Further research regarding the perception of fatigue in the arm would need to be carried out.

The results supported our hypothesis that background visual motion has an effect on ‘action’ (sustained isometric contraction), and consistent with the findings by Bruno, Milner and Franz (1995, 2001, 2001). Although the idea that perceived movement in the background can affect action, it conflicts with Bruno’s suggestion that reference frames play a significant part in ‘action’ (Bruno, 2001). With the fixed view, ‘observer related reference frames’ were minimised and movement was still observed in the hand. It would be hard to justify a unification between the various stages of planning and termination of movement but the finding contradicts Milner and Goodale’s (1995) argument to completely separate the two components in the ‘perception-action model’.

The pattern of the background did not have a significant effect on overall hand drift. However, this study only compared two patterns, and it is plausible that some differences might have a differential effect. For example, it is known that speed judgements are influenced by the level of contrast (Stone & Thompson, 1992), and further work is needed to establish if other visual factors might affect the influence of background on drift. In addition, further research would need to be conducted on the differences foreground objects and background scenery affect upper limb task and additional data will be required to make a distinction between control and non-moving conditions. This may be useful in manual labour tasks such as conveyer belt manipulation.

Acknowledgements: We would like to thank Jahangir Uddin for software programming and Ruiying Wang for technical support.

5. REFERENCES

Aglioti, S., DeSouza, J. F., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current biology, 5*(6), 679-685.

Atkins, D. J., & Robert III, H. (2012). *Comprehensive management of the upper-limb amputee*: Springer Science & Business Media.

Bridgeman, B., Kirch, M., & Sperling, A. (1981). Segregation of cognitive and motor aspects of visual function using induced motion. *Perception & Psychophysics, 29*(4), 336-342.

Bruno, N. (2001). When does action resist visual illusions? *Trends in cognitive sciences, 5*(9), 379-382.

Burke, J. W., McNeill, M., Charles, D., Morrow, P. J., Crosbie, J., & McDonough, S. (2009). Serious games for upper limb rehabilitation following stroke. *Games and Virtual Worlds for Serious Applications*, 2009. VS-GAMES'09.

Carey, D. P. (2001). Do action systems resist visual illusions? *Trends in cognitive sciences, 5*(3), 109-113.

Duncan, P. W., Zorowitz, R., Bates, B., Choi, J. Y., Glasberg, J. J., Graham, G. D., . . . Reker, D. (2005). Management of adult stroke rehabilitation care a clinical practice guideline. *Stroke, 36*(9), e100-e143.

Franz, V. H. (2001). Action does not resist visual illusions. *Trends in Cognitive Sciences, 5*(11), 457-459. doi:http://dx.doi.org/10.1016/S1364-6613(00)01772-1

Glover, S. (2002). Visual illusions affect planning but not control. *Trends in cognitive sciences, 6*(7), 288-292.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences, 15*(1), 20-25.

Honan, M., Jacobson, M., Tal, R., & Rempel, D. (1996). *Changes in wrist postures during a prolonged typing task.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society annual meeting.

Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments, 21*(4), 373-387.

Li, L., Adelstein, B. D., & Ellis, S. R. (2009). Perception of image motion during head movement. *ACM Transactions on Applied Perception (TAP), 6*(1), 5.

Mendoza, J., Hansen, S., Glazebrook, C. M., Keetch, K. M., & Elliott, D. (2005). Visual illusions affect both movement planning and on-line control: A multiple cue position on bias and goal-directed action. *Human movement science, 24*(5), 760-773.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action* (Vol. 27): England.

Moseley, G. L. (2006). Graded motor imagery for pathologic pain A randomized controlled trial. *Neurology, 67*(12), 2129-2134.

Myers, N. L., Toonstra, J. L., Smith, J. S., Padgett, C. A., & Uhl, T. L. (2015). Sustained Isometric Shoulder Contraction On Muscular Strength And Endurance: A Randomized Clinical Trial. *International journal of sports physical therapy, 10*(7), 1015.

Powell, V., & Powell, W. (2014). Locating objects in virtual reality-the effect of visual properties on target acquisition in unrestrained reaching. *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, Gothenburg, Sweden.

Powell, W., Hand, S., Stevens, B., & Simmonds, M. J. (2006). Optic flow with a stereoscopic display: sustained influence on speed of locomotion. *Annual Review of CyberTherapy and Telemedicine, 4*, 65-70.

Stone, L. S., & Thompson, P. (1992). Human speed perception is contrast dependent. *Vision research, 32*(8), 1535-1549.

Wiker, S. F., Chaffin, D. B., & Langolf, G. D. (1990). Shoulder postural fatigue and discomfort: A preliminary finding of no relationship with isometric strength capability in a light-weight manual assembly task. *International Journal of Industrial Ergonomics, 5*(2), 133-146.