Effect of game speed and surface perturbations on postural control in a virtual environment

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http://ljmu.ac.uk/rises/performance/80199.htm

ABSTRACT

The aim of this study was to describe the relationship between performance and difficulty set by altering game velocity and surface perturbations in a virtual game environment. Performance deteriorates as game difficulty increases when changing game velocity and surface perturbations. Adjustment of both game velocity and the introduction of surface perturbations independently appear to be simple and effective methods of customising task difficulty as a function of patients' motor ability during rehabilitation.

1. INTRODUCTION

Virtual rehabilitation provides the three cornerstones of motor learning which are repetitive practice, feedback about performance, and motivation to endure practice. A wide variety of methods have been used to apply virtual reality technology to enhance motor learning in people with disabilities (Holden, 2005) including assessment and rehabilitation in stroke and cerebral palsy (CP) with a specific focus on posture and balance.

Both CP and stroke are disorders which disrupt motor performance, including impaired muscle control and selectivity. Kuttuva *et al.* (2006) suggested that virtual reality can address some of the needs of stroke patients. It does this through the intensity and duration of training it can provide, through improved motivation, objective performance measures, and the ability to monitor patients at a distance. The primary abnormalities characterising CP include loss of selective muscle control, muscle imbalance and deficient equilibrium reactions. The manifestation of these abnormalities around the lower back and pelvis can be related to the concept of core stability. In spite of the primary damage to the central nervous system, motor function can be improved by controlled exercises based on the concept of neuroplasticity and this gives rise to various training methods in CP aimed at improving core stability. Several methods exist for quantifying core stability including strength measurement and electromyography of lumbopelvic muscles but it is unclear if improved core stability is associated with increased or reduced activity of muscles (Barton *et al.*, 2006). Rather than focusing on the muscular control underlying core stability, virtual environments driven by movement of the core may be used to measure and potentially improve core stability. Within the process of movement re-training, the improvement of core stability is a pre-condition of well functioning extremities and so an improvement of general movement function is expected to occur (Barton *et al.*, 2006).

Control of the core was quantified by Barton *et al.* (2006) using a virtual reality game in which a magic carpet was flown through a virtual world being driven by movement of the pelvis towards balloons appearing at random positions. It was a long term anticipation that by applying the benefits of virtual reality alongside a moving CAREN platform there would be improvements in core and peripheral stability, leading to better balance in cerebral palsy. One participant with asymmetrical CP diplegia along with one healthy subject were tested, who played a virtual reality game driven by visual and somatosensory feedback in the form of riding a magic carpet through a virtual world with the overall task of bursting balloons appearing at random positions. The game was driven by co-ordinated translation and tilt of the pelvis. It was found that the CP patient only burst around 40% whilst the healthy subject burst 100% regularly. The game's set level of difficulty was probably too low for the healthy person and too high for a patient with reduced core control due to cerebral palsy. Motivation to endure the game may come in way of finding the "sweet spot" which could be described as the level of difficulty which is not too hard to make someone give-up, but not too easy to make the person lose interest. Increasing game velocity is deemed to increase difficulty due to the phenomenon of speed-accuracy trade-off (Utley and Astill, 2008). It may also be plausible to combine the idea of altering game velocity with that of support surface perturbations particularly if these can be directed to affect the specific movements of the pelvis (tilt and rotation) which drive the game. Burtner *et al.* (1998) found that specific groups of muscles get activated in response to controlled movement of the supporting surface. They used a research paradigm using a moveable platform system to test stance balance control in adults and children. By displacing the platform unexpectedly, stance balance was perturbed in the individuals and resultant muscle responses to recover an upright posture were recorded. Adults were found to compensate for forward sway following unexpected backward platform movement by activating multiple muscles together as a functional unit.

Human balance and postural research has frequently used translational and rotational perturbations of the surface on which a person stands. Apparatus used to rotate the surface are usually constructed so their axes of rotation are constrained to run close to the platform surface resulting in non-specific movement perturbations acting on the whole body. The CAREN system (MOTEK, Amsterdam, The Netherlands) based on a Stewart platform consists of a 2m diameter platform that can be moved by six computer driven hydraulic actuators in six degrees of freedom (Fig.1) (Barton *et al.*, 2006). The CAREN platform has great potential as a research tool for postural research as it works in six degrees of freedom, independently rotating via pitch, yaw and roll, and translating via surge, sway and heave (Vanrenterghem *et al.*, 2005) because such full control of movement can be used to direct perturbations to specific body segments. An algorithm developed by Barton *et al.* (2006) was used in a number of recent studies which employed joint specific proprioceptive perturbations of balance by rotating the platform around a specific joint axis enabling the investigation of joint specific balance correction strategies beyond the conventional ankle and hip strategies (Barton *et al.*, 2005). The systematically determined kinematic response characteristics of the CAREN platform by Lees *et al.* (2007) lead to a conclusion that the CAREN system is an appropriate device for postural and balance research. Current research with this platform also includes a study by Foster *et al.* (2008) which investigates movement co-ordination of the pelvis in a virtual game environment. Here the CAREN system was used in conjunction with virtual reality to evaluate core control and pre-established patterns of co-ordination within the game environment.

The aim of this study was to describe the relationship between performance and difficulty set by altering game velocity and surface perturbations in a virtual environment.

Figure 1. *The CAREN platform (MOTEK, Amsterdam, The Netherlands) can generate targeted movement perturbations which can be used to control game difficulty.*

2. SUBJECTS/MATERIALS AND METHODS

Four healthy male volunteers (age: 19-23 years) were trained to play the magic carpet game, allowing them to adapt to the game environment and learn the control schemes at a standard default level of game speed (40 m/s) and without surface perturbation. A virtual reality game used by both Barton *et al.* (2006) and Foster *et al.* (2008) was employed where the task is to fly a magic carpet through a virtual world bursting balloons appearing in seemingly random positions. The subject controls the game by moving the pelvis in a way as to move the magic carpet both vertically and horizontally driven by simultaneous pelvic tilt and rotation. Visual feedback on the subject's movement was generated by the CAREN system (MOTEK, Amsterdam, The Netherlands).

Three dimensional orientation of the pelvis was determined by real-time tracking and recording of the movement of 3 markers attached to the PSISs and the sacrum using 8 Vicon 612 cameras (Fig. 2). Transverse plane rotation and sagittal plane tilt of the pelvis was driving the carpet sideways and vertically respectively towards balloons appearing at random positions. Where the balloons appear within the game is pre-determined in their trajectory but appear random to the participants.

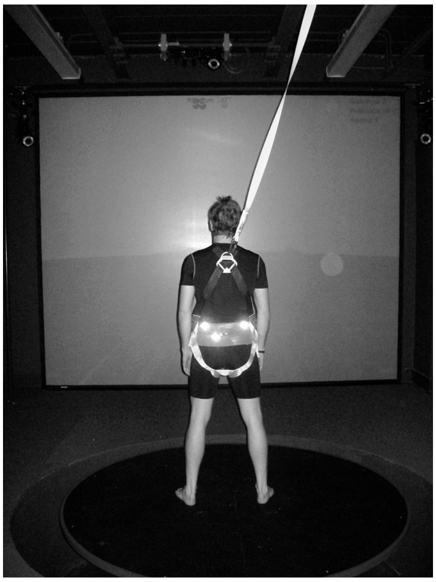

Figure 2. *The participant is standing on the CAREN platform with a cluster of reflective markers attached to the pelvis; driving the game, and flying the magic carpet through the virtual world. The platform acts as a stable base when carpet velocity is increased and can introduce surface perturbations whilst the subject endeavours to burst balloons.*

The participants undertook a number of trials over a pre-determined set of trajectories (Fig. 3), potentially bursting up to 225 balloons based on a 200 displacement stimuli for each trial. Difficulty settings for the game were defined by carpet velocity at 30 m/s, 40 m/s, 50 m/s, 60 m/s, 70 m/s and default gain settings (Tab. 1). The participant progressed to the next velocity when regularly bursting at least 7 out of 9 balloons. If the subject was unable to achieve this, they ran through a full set of the trajectories before moving up a level. One of the 8 pre-determined trajectories was selected for analysis which ensured the subject was tilting and rotating the pelvis at the same time, so as the participant completes a multiple task controlling two degrees of freedom of the pelvis simultaneously. The averages of all instantaneous distance curves from the carpet to the balloon in the coronal plane were plotted together with ± standard deviation (SD) indicating variability of performance, for all five velocities. The measure of performance was quantified by the area under the distance curves normalised to the duration of approach. Additionally, the maximum standard deviation (SD_{max}) was used as a measure of performance variability.

Following this set of data collection participants were brought back into the laboratory to investigate the relationship between performance and platform movements. The same subjects firstly undertook a full set of 225 trajectories at default gain levels and at a carpet velocity of 40 m/s, to re-familiarise themselves with the game.

The CAREN platform moves in six degrees of freedom allowing it to rotate (pitch, yaw, roll) and translate (surge, sway, heave). The subjects undertook three levels of the magic carpet game with default gain settings and carpet speed at 40m/s, but with the platform moving randomly driven by a series of overlapping sinusoidal waves to define carpet movement in a specific degree of freedom. The three levels were defined as Surge, Yaw, and SurgeYaw (combining both movement in the Surge and Yaw levels), moving the carpet so as to force sagittal plane tilt (influenced by platform Surge) and transverse plane rotation of the pelvis (influenced by platform Yaw), henceforth disrupting the task of driving the carpet. The averages of all instantaneous distance curves from the carpet to the balloon in the coronal plane were again plotted together with ± standard deviation (SD) indicating variability of performance, for the three platform movement levels. The measure of performance was again quantified by the area under the distance curves normalised to the duration of approach. The maximum standard deviation (SD_{max}) was also used again as a measure of performance variability.

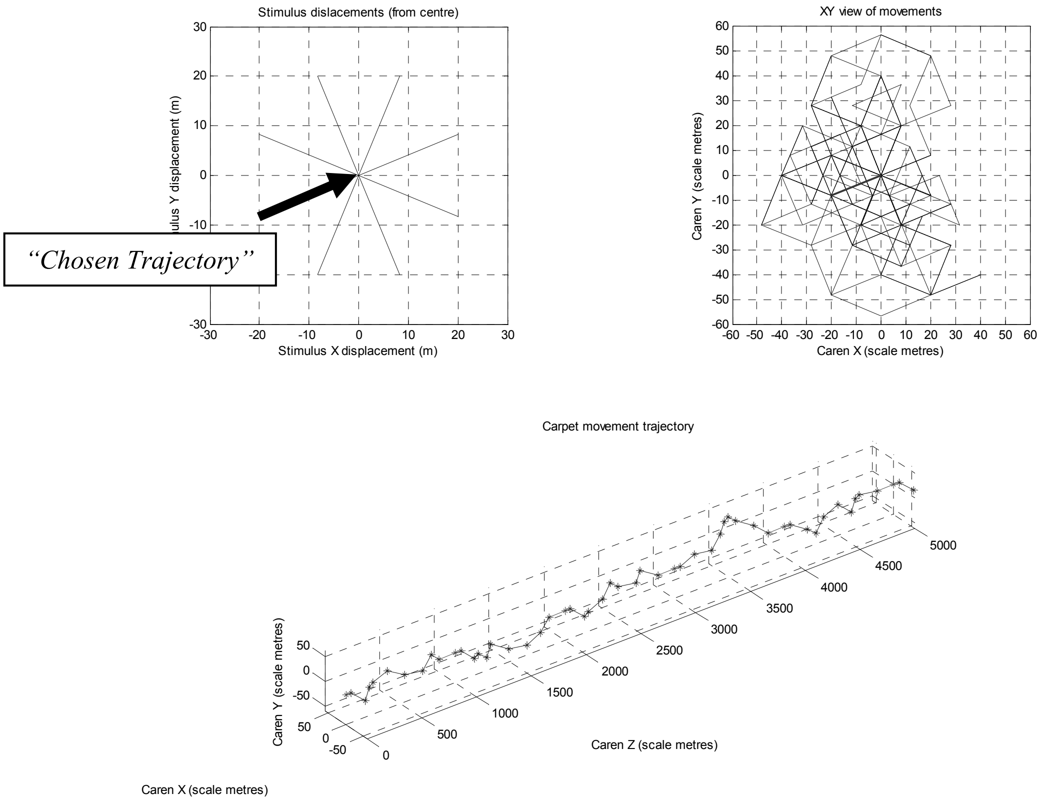

Figure 3. *The top-left plot shows an X-Y plot of the eight trajectories. The top-right plot shows the X and Y range of 200 trajectories (25 x 8) presented in blocks of eight in random order within each block. The 3D plot shows an isometric view of the first five sets of eight trajectories plotted end to end. The chosen trajectory incorporates both movements of the pelvis involved with the control scheme: pelvic tilt and rotation.*

Table 1. *Default Magic Carpet gain settings. Gain was changed proportionally to velocity.*

Level	Velocity (m/s)	X gain (m/s/deg)	Y gain (m/s/deg)
1	30	1	0.5
2	40	1.33	0.67
3	50	1.66	0.84
4	60	2	1
5	70	2.33	1.17

3. RESULTS

Figure 4(a-f) represents the averaged results for all subjects at the specified trajectory. Graphs (a-e) show that there is a lack of movement towards the target at the beginning of the specific trajectory (first 0.5 s) and the linearity of the curves after this initial decision making increases as carpet velocity increases. The variability (SD) increases gradually as carpet velocity increases [Fig. 1(a-e)], and its maximum occurs around the point of transition from decision making to pelvic movement. The area under the curves also increases as carpet speed increases [Fig. 1(a-e)]. These results for normalised areas under the curves, and variability (SD_{max}) are shown graphically in figure 1(f).

A one-way repeated measures ANOVA test showed significant differences in the area under the curves, ($F_{2.164,\ 6.491} = 11.832$, $P < 0.05$), and for the variability of movement (represented by maximum standard deviation; $F_{2.288,\ 6.865} = 11.735$, $P < 0.05$) for all subjects. Post-hoc analysis showed that normalised area under the curve at 50 m/s was significantly greater than that at 30 m/s and that the normalised area under the curve at 60 m/s was significantly greater than that at 30 m/s and 40 m/s. Post-hoc analysis also showed that the variability for 70 m/s was significantly greater than at velocities 30 m/s, 40 m/s and 50 m/s.

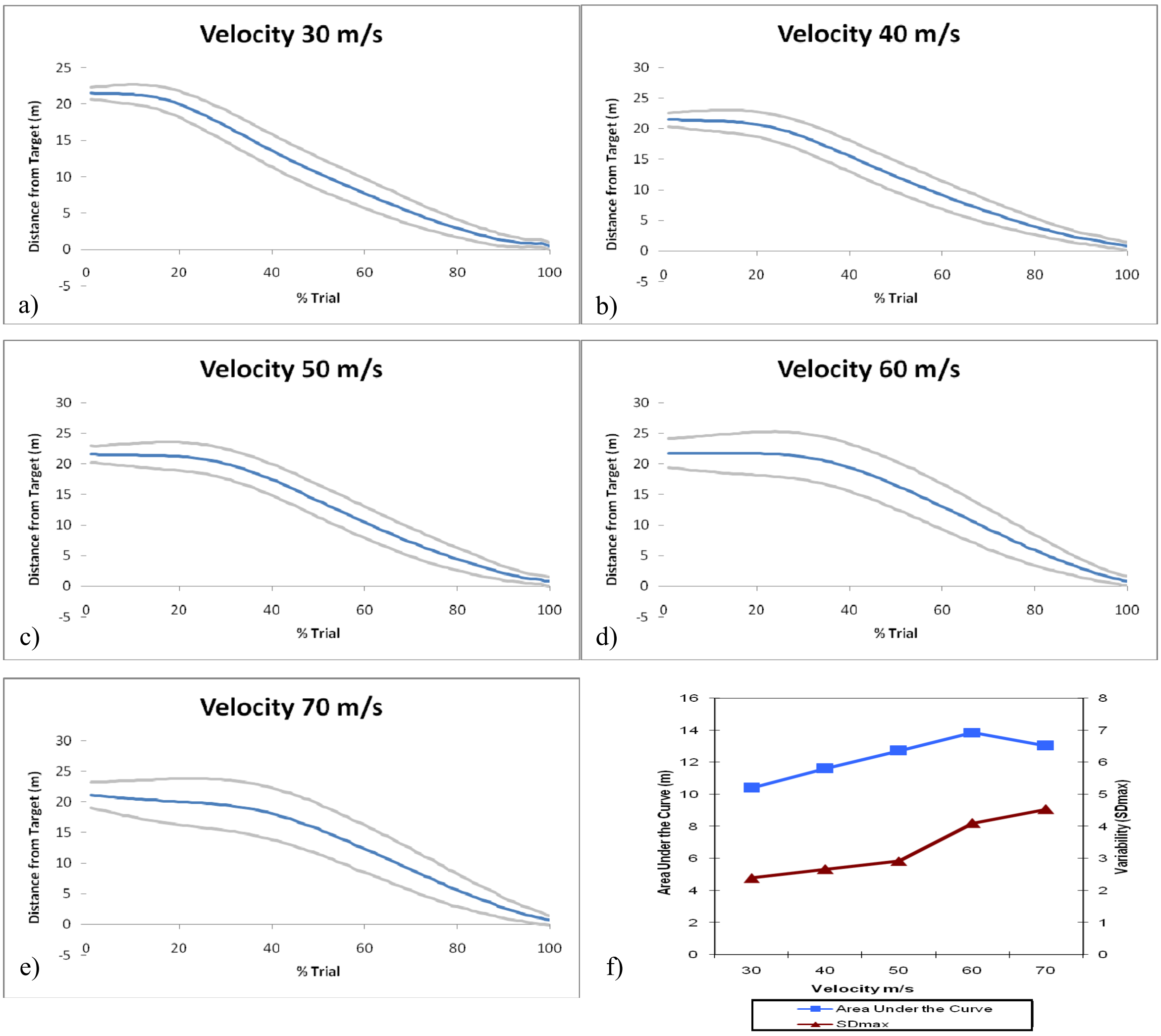

Figure 4. *(a-e) Distance – time graphs for all subjects at all test velocities. (f) Normalised area under the curve and variability results as a function of game velocity.*

Figure 5(a-f) represents the averaged results for all subjects at the specified trajectory under the four conditions of no support perturbation (NoSP), Surge, Yaw, and combined SurgeYaw. Graphs (a-e) again show similar characteristics to those in figure 4b, when the same carpet velocity was used (40 m/s). The variability (SD) curves for all surface perturbation test graphs are similar. Differences do appear however at the start of the approach, where variability is larger in Surge and Yaw than NoSP and even more so in Surge Yaw.

A one-way repeated measures ANOVA test showed no significant differences in the area under the curves, ($F_{1.557, 4.672} = 1.018$, $P > 0.05$), and for the variability of movement represented by maximum standard deviation ($F_{1.622, 4.866} = 0.333$, $P > 0.05$) for all subjects.

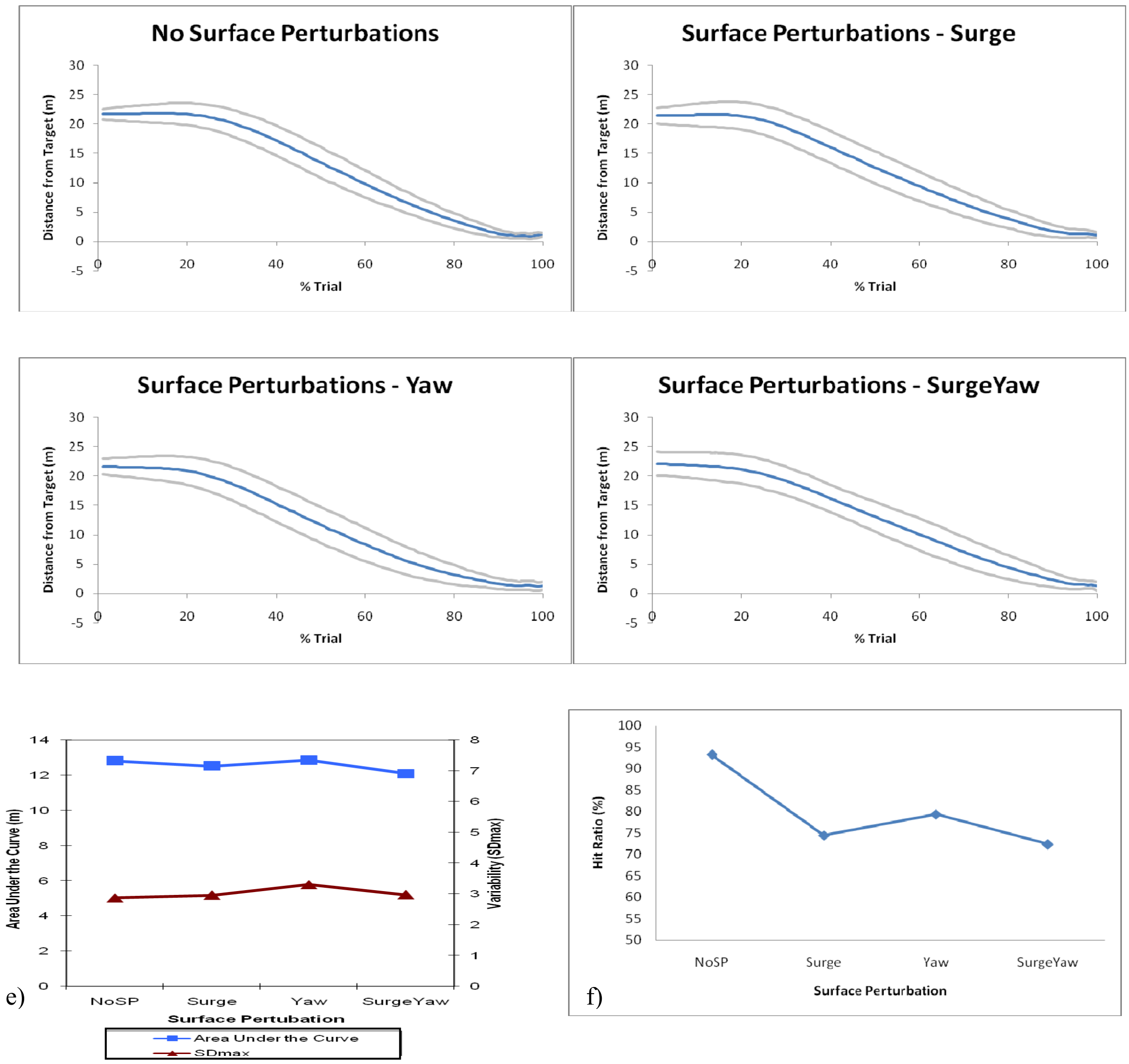

Figure 5. *(a-d) Distance – time graphs for all subjects at all test surface perturbations "No Surface Perturbations" (NoSP), "Surge", "Yaw" and "SurgeYaw". (e) Normalised area under the curve and variability results as a function of surface perturbations. (f) Average balloon hit percentages for all subjects across all test surface perturbations.*

Although no significant differences were found between performance measures and type of surface perturbation, when looking at a hit percentage graph [Fig. 5(f)] it is clear that the hit percentage decreased when surface perturbations were introduced. A one-way repeated measures ANOVA test showed significant differences in hit percentages, ($F_{1.526,\,4.578} = 8.127$, $P < 0.05$) across all subjects. Post hoc analysis showed that balloon hit ratios at Surge, Yaw, and SurgeYaw surface perturbation tests were all individually significantly different from No Surface Perturbations (NoSP). Post hoc analysis also showed that there were no significant differences between types of surface perturbation.

4. DISCUSSION

Initially there is no movement towards the target and this represents a phase of decision making as to how to move the pelvis in order to drive the magic carpet towards the balloon. Linearity of the curve after the initial decision making period increases with velocity, showing that there is a need for a more direct approach to the balloon at higher game velocities. The maximum point of variability appears to occur at the beginning of pelvic movement, where the subject makes initial adjustments. Taking the above into consideration we could divide the trajectory into three sections of decision making, initial adjustments, and minor corrections.

Statistically as carpet velocity is increased, performance (defined by area under the curves and maximum variability) deteriorates. We can discover a threshold of velocity above which the game becomes more difficult. Post hoc analysis shows that 30 m/s, 40 m/s, and 50 m/s levels produce significantly lower results than those at 60 m/s and 70 m/s levels. However, 30 m/s, 40 m/s, and 50 m/s levels are not significantly different from each other and neither are 60 m/s and 70 m/s levels. We can therefore say that a difficulty threshold lies between 50 m/s and 60 m/s levels.

A limitation of the velocity results as an indication of performance is that of the discovered decision making phase. Since the decision phase appears to be relatively constant at all carpet velocities, then the area under the graph results will naturally increase, due to the longer block taken up by the decision making phase.

When looking at graphs representing difficulty changes by introducing surface perturbations, the trajectory can again be divided into the identified three sections previously described. However, surface perturbation test graphs all show similar curves, with similar areas under the graphs, which was backed up by the statistical tests showing no significant differences in different types of surface perturbation. We can however see slight differences at the start and end of the trajectories when looking at variability. The variability is low for NoSP, suggesting a smooth exit from the previous trajectory, whilst for individual surface perturbations Surge and Yaw, the variability is slightly larger. This change is more noticeable in SurgeYaw when a dual surface perturbation is introduced, suggesting it is more difficult to target the following balloon at this surface perturbation level. It may also be fair to say that SurgeYaw variability is changing throughout the movement, represented by a double bump of the SD range in the initial adjustments phase.

Although it appears that the game does not become more difficult when introducing surface perturbations, as shown when using area under curves and variability as performance measures; if balloon hit ratio is taken into consideration, results differ. Using hit ratio as a performance measure showed that the game became significantly more difficult as average scores of 95% dropped by around 20%. It is therefore fair to say that the introduction of surface perturbations does make the game more difficult. Furthermore, post hoc analysis showed that it does not matter what type of surface perturbation was introduced as there were no significant differences between types of surface perturbation tests.

5. CONCLUSIONS

Game velocity appears to be a simple and effective means of increasing difficulty of the game when measuring core control and customising task difficulty as a function of patients' motor ability during rehabilitation. Such manipulation of difficulty may be necessary to more accurately quantify movement performance of patients with a widely ranging level of motor abilities, while maintaining their motivation during the protocol. Introducing surface perturbations may also be used in a similar way, but only if hit ratios of balloons burst are used as a performance measure and only when the game velocity is set to 40 m/s; further research into a relationship between game velocity and surface perturbations may be useful. Further research into a relationship between surface perturbations introduced and control mechanisms, such as pelvic tilt and rotation gain settings may also be necessary in order to establish whether area under the curves and variability can be used as performance measures when introducing surface perturbations.

The results gained from healthy participants establish baseline data which may be used as a reference for non-healthy participants such as those with CP. Further testing must be carried out on non-healthy subjects applying what has been learned from this study in order to develop appropriate game settings, which can be used in a rehabilitation programme, in order to evaluate and improve core control.

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