QUANTIFYING UPPER LIMB MOTOR CONTROL: THE PEG IN HOLE TEST

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INTRODUCTION

The *I-match* project (www.i-match.org), funded by the European Commission under the Information Society Technologies program, is a three-year project that began in 2002. It focuses on quantifying user's upper limb performance and skills in order to aid in selecting the most suitable interface for use with an assistive device. Within this project a new technique, the 'Peg in Hole Test' was developed making use of virtual reality and haptic robotics in order to access motor control.

The Peg-in-Hole assessment is essentially a 3D movement task presented in a virtual space (Figure 1). It has a simple geometry and objective. It consists of a table with two cylindrical holes and one cylindrical peg that is to be placed in the holes alternately using the hand. It is inspired by the validated, used in clinical assessment, Nine-Hole-Peg-Test [1].

METHODS

The PHANToM haptic interface (SensAble Technologies, USA) was used. It offers 3 active and 3 passive degrees of freedom. The orientation of the virtual peg follows that of the PHANToM stylus in real-time. Shadow cues are used to provide better depth perception and a novel collision detection algorithm was developed, allowing for multiple contacts points between the peg, the table and holes and the walls thus adding realistic touch feeling. The peg insertion and removal is preceded by a guiding arrow and a beep sounds at each successful peg insertion. It is possible to modify, on the fly, the peg diameter, peg height and weight, hole diameter, separation between holes and clearance (peg vs. hole) .

A pilot study involving 12 healthy subjects (6 females, 6 males, age 32 ± 8) was conducted. Subjects were instructed to (starting from mid-position) insert the peg into the left hole, remove it and insert it into the right hole as quickly as possible while trying to minimise the collision with the table and the walls of the holes. This was performed 20 times (10 cycles) before moving to the next experimental setting.

Two virtual tables were selected: one with a separation between holes of 50mm and the other 150mm. The diameter of the holes was set at 20, 30 and 40mm. Two peg weights were used: one with simulated weightless (0 N) and the second with a weight of 0.981N (~100g). The virtual peg diameter was set constant at 10mm. These combined variables made for a total of 12 different testing conditions.

Data was logged at an average sampling frequency of 1000Hz. Forces, positions, orientations and velocities were recorded. In order to exclude learning effects, only 5 full cycles were analysed (cycles 4 to 8) for each of the 12 settings.

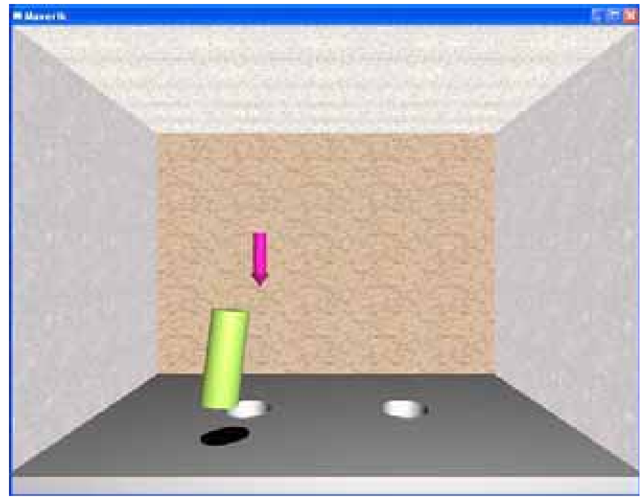

Figure 1: The Peg-in-Hole test

RESULTS AND DISCUSSION

The following results were calculated from the 144 tests: time of each full cycle, time of left-to-right and right-to-left half-cycles, FFT, spread of velocities, collision energies, spread of positions at mid-travel and at insertion for right and left holes, deviation of Y positions from a straight line and deviations from Fitts law [2].

All frequencies were below 0.5Hz and corresponded to the gross movement (no tremor). Adding weight appeared to lower collision energy. The accuracy and repeatability of the movements were analysed using the distribution of positions (error and STD) at bottom of right and left holes ($z = 0$), these varied with the clearance and the side considered.

X-Y plots showed a consistent double arched pattern clearly different from the expected shortest projected path (straight line fits produced RMSE>0.8). Fitts 'law' failed to apply, the movement time did not correlate linearly to index of difficulty.

CONCLUSIONS

It appears that a more compressive measure of "difficulty" of a task must be introduced. Real world human arm movement tasks are in nature 3D, have a goal, might involve obstacle avoidance and eventually face collisions. The Peg-in-Hole test, despite its simplicity, has embedded in its design all of these factors and as such can be a powerful tool in studying and accessing general upper limb movement. A single compounded factor involving collision energy, duration of collisions, repeatability, accuracy and cycle time of the movement may prove to be a more realistic measure of quality or difficulty of these movements.

REFERENCES

1. Wade, D.T., *Measurement in Neurological Rehabilitation*. 1992: Oxford University Press. 408.
2. Fitts, P.M., The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 1954.**47**:p.381-391