

# Robotic psychophysics rig to assess, diagnose and rehabilitate the neurological causes of falls in the elderly

Chin-Hsuan Lin<sup>1</sup>, MD and A. Aldo Faisal<sup>1,2,3</sup>, Member IEEE

**Abstract**—Falls are the leading causes of unintentional injuries in the elderly and thus a pose a major hazard to our ageing society. We present the FOHEPO (FOot HEight POsitioning) system to measure, diagnose and rehabilitate ageing-related and neurological causes of falls. We hypothesise that both perceptual and motor variability is likely to increase with age and may lead to imprecise movements causing trip overs, the major triggers of falls. Here we propose a robotic system that automatically performs measures of fall-related perceptual and motor variability in elderly subjects. Our FOHEPO platform enables us to measure and track different sources of noise in the nervous system: visual perception noise of obstacle height, proprioceptive noise of localising raising one's foot to a desired height, noise in the visual feedback of the foot movements. The platform should eventually provide us the means to estimate fall probabilities by using these measures. Crucially, we can use the same system in game-field settings to rehabilitate elderly users moving with larger safety factors so as to reduce their risks of trip-over.

## I. INTRODUCTION

Many fundamental health challenges faced by modern societies are caused by rapid population ageing. Falling constitutes one such challenge and is the leading cause of unintentional injuries in the elderly [1]. Falls result in injuries [2], reduced life quality [3] and decreased survival [4]. Comprehensive studies using symptomatic descriptions or biomechanical measurements have made significant progresses in the understanding of falls in the elderly [5], [6], [7]. However, less has been done to understand falls from a computational and motor neuroscience way. Computational principles in motor control enable us to connect ageing-related brain pathology to changes in biomechanical and physiological markers – and in the end to falls themselves.

One key aspect is obstacle clearance, the minimum distance between the inferior surface of foot/shoe and the obstacle when stepping over it: Clipping the obstacle due to negative clearance will result in a trip event – which are the major main cause of falls in the elderly [8]. However, the mechanisms causing a decrease in the performance of obstacle clearance in fall-prone elderly people remain unexplored. Both active obstacle clearance (consciously increasing obstacle clearance) and an increase in obstacle clearance variability [6] were found to link to increased risks of falling. The former variability we associate with sensory/perceptual noise about the height of the obstacle, the

letter variability we associate with variability in movement trajectories, contributed by motor noise. We propose that age-related changes of sensory and motor uncertainty, as well as the sensorimotor computations that mitigate uncertainty (cue integration and motor coordination), cause the alteration of obstacle clearance in potential elderly fallers. To tackle these questions we require controlled experiments that capture the sensorimotor loop (perception, action, environment) and therefore requires the targeted development of experimental set-up in which to study these.

Here we designed a controlled robotic psychophysical testing environment to present subjects with naturalistic, yet highly controlled stimuli, that enable us the estimation of sensorimotor noise and integration in lower extremities. Also, using this paradigm, we tested our hypothesis of increased noise level as a cause of increased obstacle clearance variability in aged people. We devised foot height positioning task (FOHEPO), a task adapting clearing an obstacle, to measure sensorimotor variability. Unlike real obstacle clearing. Our foot height positioning task does not endanger subjects being in contact with an obstacle and therefore has minimal risk of falling, yet it mimics the scientifically relevant elements of obstacle clearing.

## II. METHODS

### A. Design of the FOHEPO rig

The FOHEPO (FOot HEight POsitioning) rig (Fig 1.) involves a robotic automated platform, hand rails to support subjects, as well as motion tracking devices and a computer system. Our system allows a close-loop interaction of human subjects and a computer-controlled experimental paradigm. The general experimental set-up consists of an one side open metal rig (length 1180mm × width 800mm × height 1040 mm, open side: 800 mm) with bilateral handrails. Our automated movable target is 900mm away from a subject. This suffices the usual distance when an observer has to clear o obstacle avoidance during ambulation . Four Firgelli (Firgelli, Victoria(BC/Canada) linear actuators (Firgelli L16-140-63-12-S) are operated synchronously via Arduino Uno micro-controllers to move the object between trials. The is made of a white polystyrene sheet length 760 mm x width 300 mm x thickness 5 mm. Since the floor and walls of the rig are covered with black floor mats and cardboards, there is a sufficient visual contrast between the target and its surroundings (Fig. 1. C).

During the experiment, the positions of subjects' moving foot and the target as well as their relative height differences are constantly monitored by three motion capture cameras

Brain & Behaviour Lab - <sup>1</sup>Dept. of Bioengineering & <sup>2</sup>Dept. of Computing, Imperial College London, South Kensington Campus, SW7 2AZ, London, UK, <sup>3</sup>Imperial Clinical Research Facility , Imperial Centre for Translational and Experimental Medicine, W12 0NN London, UK - a.faisal@imperial.ac.uk

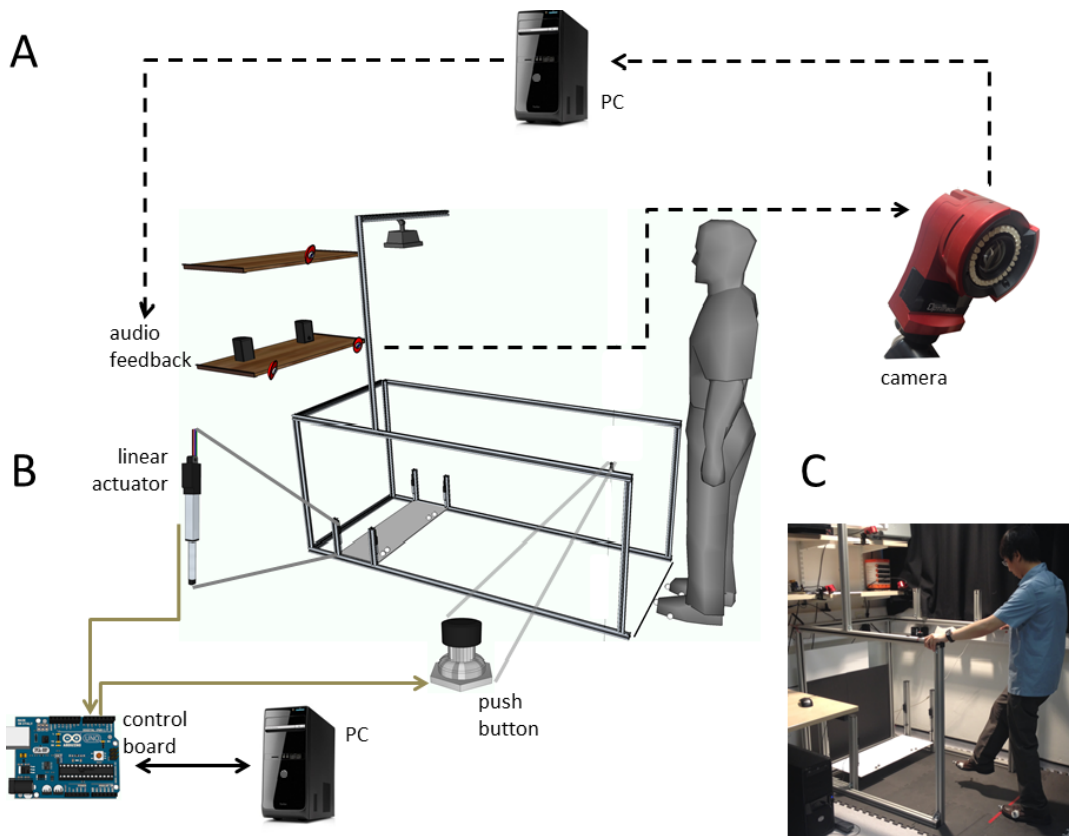


Fig. 1. Experimental setup: (A) displays the system's components which interact during an actual experimental session and also provide online feedback of the monitored performance measured by the motion capture system (B) The object position is controlled by a PC-run software module, through Arduino Uno micro-controllers. The button sending signals to the PC also connects via the micro-controller (C) The setup in the laboratory

at 120 Hz (Optitrack Flex 13; NaturalPoint, Inc. Corvallis(OR/U.S.A.)). Our system were tested by using objects with known heights of 90 mm, and was proved to provide excellent precision and stability. The mean error is 0.5 mm and the drift over 1 hour is less than 0.05 mm.

### B. Experimental Protocol for the Foot Height Positioning Task (FOHEPO Task)

In all trials, subjects are required to lift one of their feet to match the height of the shoe tip marker and the target. They are asked to keep their feet level. However, in order to keep a natural body positioning and allow the subjects to use visual information of their foot positions, movements along the sagittal plane of their bodies are suggested. Before the beginning of each trial, actuators move the target to a pre-set height. Three consecutive beeps of 0.1 sec duration and 0.85 sec inter-beep interval are played for 2 sec once the object reaches its target level. The first two beeps are served as warning signals for subjects to get prepared. The last beep is the signal to move. Subjects are asked to reach the target level as fast and accurate as possible. They are instructed to press a button on the left handrail when they consider their foot matches the target height. After pressing the button they have to keep their foot still for 1 sec before hearing another audio signal, which indicates the end of this trial and also provides performance feedback (positive when the difference between the foot and the object less than 35 mm; otherwise

negative). The start of a trial is defined as the moment when the third beep begins. If a subject does not press the button within 4 seconds after a trial starts, this trial is terminated automatically and labelled as a "mis-trial". Subjects redo all mis-trials at the end of every block. If a subject still fails to complete a trial within 4 second in one's second try, that trial is excluded from data analysis.

Three height conditions, 50, 100, 150 mm, are used to prevent stereotypical behaviours and self repeating. Also, this height range covers usual human step height both in walking and in stair-climbing. Heights are chosen in pseudorandom orders. There are 40 trials per condition, 20 for each foot. Trials are separated into 4 blocks. Alternative foot order are used (either R-L-R-L or L-R-L-R).

For each trial, the average of all foot height data acquired during the 1 second after button press is taken as the foot height. 'Movement time' is calculated by subtracting the beginning time of the final beep from the time button pressed. The primary outcome are the mean variance and standard deviation of foot height for each condition and each foot, as the quantification off sensorimotor noise, and the mean of foot height for each condition each foot as the precision of foot placement.

### C. Psychophysics technique to measure sensory noise

To better understand how sensory noise can be estimated by psychophysics, we apply a psychometric function in

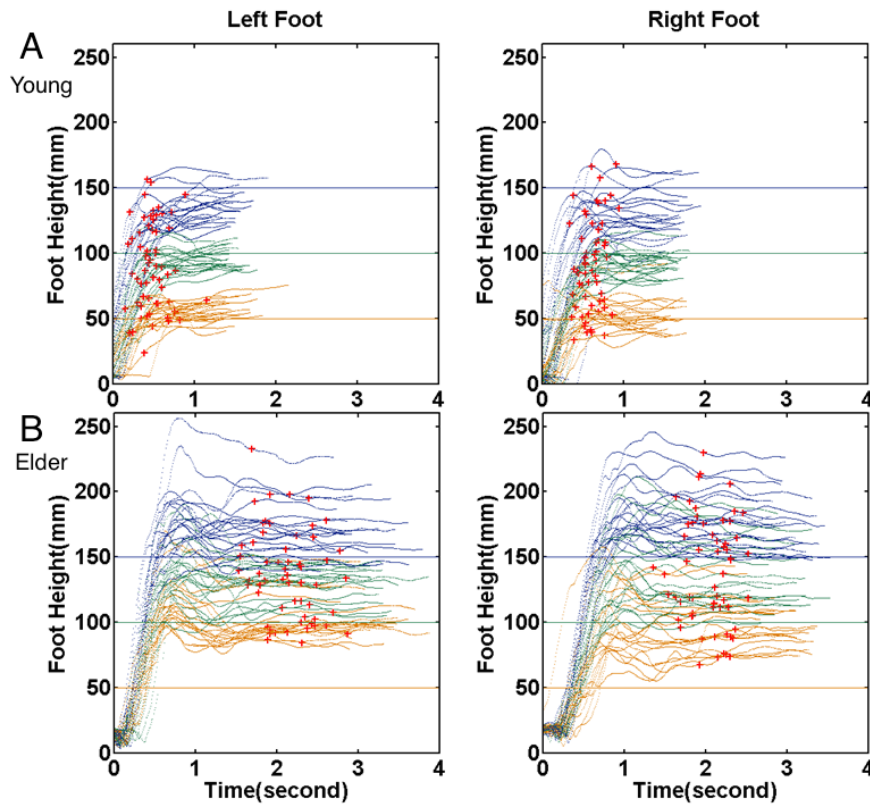


Fig. 2. Foot height trajectories for height matching task (lift up of foot from 0 to 50, 100, 150mm target height) for left and right foot. **A** Young subject **B** Elderly pilot subjects. trajectory over time in A.a healthy young pilot B. a healthy elderly pilot. The red crosses are the time when the rig's button was pressed to signal task completion.

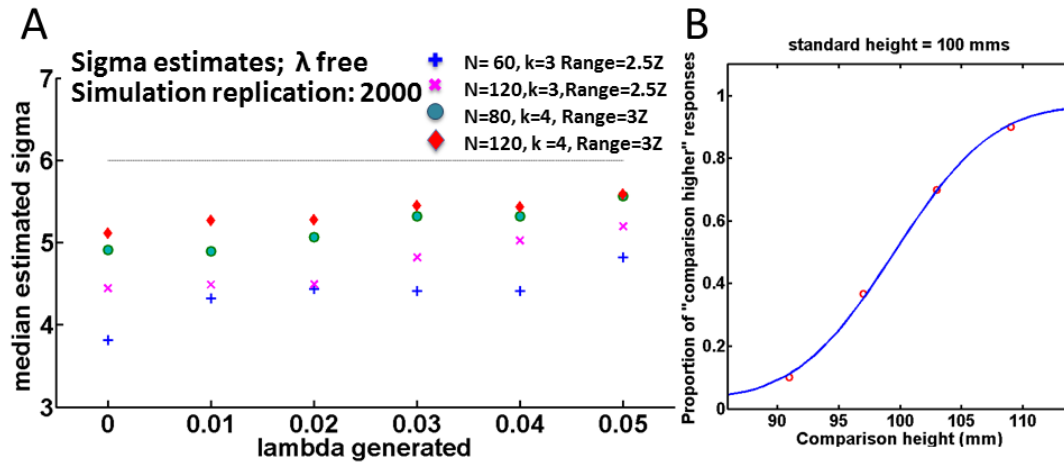


Fig. 3. **A** Simulated results of median estimated sigma using 4 different combinations of trial number (N), number of stimulus level (k) and stimulus range (Range, in Z unit). Simulation methods were adapted from Simulatory observers' lapse rate lambda values were set to be one of 0, 0.01, 0.02, 0.03, 0.04, 0.05. **B** Using parameters which generated best-fitted results in A (N=120, k=4, Range= 3Z), object 2AFC was performed with a young volunteer. The results and fitted psychometric function are presented.

the context of signal detection theory (SDT) [9]. SDT assumes that the strength of each sensory input is internally represented as independent Gaussian variables. In 2AFC discrimination tasks, SDT can be comprehended by a simpler difference distribution of internal sensory responses. On each trial, observers compare the difference between two internal responses and pick the stimulus based on the sign of the

difference. We assigned standard stimulus intensity to be  $s$  and comparison stimulus with varying intensity across trials to be  $c$ . If the probability density functions of the internal representation for  $s$  and  $c$  are Gaussian with identical variance  $\sigma^2$ . The psychometric function is the Gaussian cumulative density function of observed difference distribution with variance of  $2\sigma^2$ . Therefore, acquiring a psychometric

function experimentally provides an estimate for the noise of the underlying distribution.

Object height and foot height 2AFC tasks are used to characterise visual noise of object height estimation and proprioceptive noise of foot height estimation. In all sensory tasks, subjects are standing in the robotic experiment environment the same as the one in FOHEPO. In object 2AFC, subjects choose the higher interval in each trial. In foot height 2AFC, Subjects are asked to choose if the passively moved foot or the object is higher. Here, one of their feet will be lifted and supported by a small-sized platform. Therefore, motor noise is minimised, if not eliminated, while sensory noise is retained. Experiment is divided into two phases where 1. the moving foot is visible 2. the moving foot is occluded. Both phases enable subjects to quantify body(foot in this experiment) position sensory variability when subjects receive both visual and proprioceptive information (first phase) and when they only have proprioceptive information (second phase).

### III. RESULTS

The FOHEPO system was tested with a healthy young and a healthy elderly subject. Both subjects completed the FOHEPO tasks within 40 minutes. As can be seen from the movement trajectories (see Fig 2.A,B), the young subject typically had shorter movement time, pressed the button earlier and thus completed trials faster than the elderly subject. No significant difference between feet were noted in the means and standard deviations of foot height and movement time. Therefore, data from both feet were pooled together for further analysis.

The elderly volunteer showed a higher degree of foot placement variability comparing to the young counter part (standard deviation at 50-100-150 mm: young: 10.2 mm-8.7 mm-15.2 mm; elderly: 18.4 mm-27.0 mm-22.1 mm). This finding is in agreement with our hypothesis. Interestingly, the elderly subject tended to place his foot higher (mean 101.7 mm-130.2 mm-175.2 mm) than the younger counterpart (52.5 mm-93.0 mm-128.9 mm) and the real object height, suggesting perhaps an age-dependent increase in safety factors for foot clearance.

To obtain an accurate estimate of  $\sigma^2$ , more than 240 trials are suggested by literature [10]. However, our trial number is limited by the characteristic of our study population, elderly people, and instruments, a linear motor controlled moving object. Computing simulation and pilot experiments were used to determine optimal trial number, condition number and stimulus range for our psychophysics experiment. We found a design with  $N = 120$  trials, number of conditions = 4 and stimulus spacing of 18 mm providing us a satisfying result for object 2AFC(Fig 3.A,B). Our young subject completed the experiment in 45 mins. Using the same design, trial numbers in foot 2AFC can be doubled to 240 without increasing total experiment time since there is only 1 interval for each trial.

### IV. DISCUSSION

We designed a closed-loop robotic environment for the research of sensorimotor uncertainty and control in lower extremities. Our FOHEPO provides an undemanding method to understand the relationship between sensorimotor uncertainty and fall risk in elderly people systematically. We implemented the FOHEPO in one young and one elderly volunteer. Preliminary results were compatible with our assumptions. Larger foot placement variability, higher foot placement, and longer movement time were observed. More subjects will be included in order to prove the hypothesis. Individual elements of sensory noise will be extracted using psychophysics. By doing so, the contribution of each element to ageing-related changes in sensorimotor uncertainty can be clarified.

Potentially, the methods can be applied to high risk elderly groups and patients with fall-prone neurological disorders, such as Parkinson's disease and Alzheimer's disease, to elucidate the underlying mechanisms causing falls in these conditions. Moreover, the robotic environment can be used as an assisting rehabilitation tool for fall prevention in high risk groups.

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