**THE MOVEABLE HANDHOLD: A NEW PARADIGM TO STUDY VISUAL
CONTRIBUTIONS TO THE CONTROL OF BALANCE-RECOVERY REACTIONS**

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ABSTRACT

Balance-recovery reactions that involve rapid step or reach-to-grasp movements are prevalent and functionally important responses to instability. Successful use of these reactions to recover balance in daily life requires a capacity to modulate the reaction to deal with the continual variation in environmental constraints that occurs as the person moves, i.e. location of objects that can obstruct limb movements or serve as handholds to grasp. The most direct approach to study this involves applying balance perturbations as subjects move within a visually-complex environment; however, this approach does not allow precise control over kinematic variables or visual inputs, and is susceptible to strong learning effects. We have therefore developed an alternate approach, wherein the subject is stationary and the relative motion between subject and constraints that normally occurs as a result of ambulation is instead introduced via movement of surrounding obstacles or handholds. We previously developed a motor-driven “obstacle-mover” to manipulate constraints on step reactions, and now describe an analogous approach to study reach-to-grasp reactions, using a motor-driven “handhold-mover”. We anticipate that this paradigm will provide new opportunities to probe CNS control of upright stance, by providing a sensitive indicator of limitations in the neuromusculoskeletal systems. It can also be used to test perturbation-evoked reactions in seated subjects, thereby allowing testing or training of persons who are unable to stand and use of techniques (e.g. TMS, EEG) that can be difficult to perform in free-standing subjects.

INTRODUCTION

Balance-recovery reactions that alter the base-of-support, via rapid step or reach-to-grasp limb movements, play a crucial role in preventing falls [1]. However, successful use of these “change-in-support” reactions, in daily life, is likely to depend heavily on the ability to modulate the reaction to deal with the continual variation in environmental constraints that occurs as the person moves, i.e. location of objects that can obstruct limb movements or serve as handholds to grasp. There is a need to understand how the central nervous system (CNS) acquires the visuospatial information needed to guide step and reach-to-grasp reactions amid changing environmental constraints; however, research in this area has been hampered by methodological difficulties.

METHODOLOGICAL ISSUES

The most direct approach is to apply a balance perturbation as the subject moves within the environment, and record the gaze behaviour that occurs before and after perturbation-onset (PO). For example, a large motion-platform can be used to apply the perturbation, while providing a visually-complex “real-life” environment with constraints on foot placement (clutter on floor, stairs, etc.) as well as potential handholds to grasp (handrails, furniture, etc.) [2,3]. While this approach can provide invaluable information regarding natural behaviour, there are a number of practical limitations: 1) variation in gait precludes precise control over the position and motion of the body, in relation to the constraints, at PO; 2) this variation also precludes precise control of central and peripheral visual inputs; 3) subjects are likely to learn proactive strategies after a small number of trials (e.g. grasp handholds prior to PO). The latter limitation may be prohibitive in studies requiring multiple within-subject assessments, e.g. before and after balance training.

To avoid these methodological problems, we have developed an alternate approach to introduce spatio-temporal variation in environmental constraints prior to PO. Here, the subject is stationary and the relative motion between subject and constraints that normally occurs as a result of ambulation is instead introduced via movement of surrounding obstacles or handholds.

Previously, we developed a motor-driven system to manipulate constraints on step reactions by varying the location of obstacles surrounding the subject [4]. We now describe an analogous approach to study reach-to-grasp reactions, using a motor-driven “handhold-mover” (HHM). The HHM can be used to reposition the handhold before PO or after PO (e.g. during the reaching phase of the reaction).

Ability to study reach-to-grasp reactions is important for several reasons. Because these reactions are functionally important in preventing falls, clinicians need to understand effects of aging, injury and disease [1]. Studying reach-to-grasp reactions also presents unique opportunities to probe CNS control of balance. Such reactions are likely to be one of the most challenging aspects of balance control, particularly when graspable objects are restricted in size or location, or the opportunity to view them is limited. Thus, testing these reactions can provide a sensitive indicator of limitations in the neuromusculoskeletal systems. This also provides opportunities to assess CNS control of balance in seated subjects [5]. It then becomes possible to test or train patients who are unable to stand (e.g. stroke), control confounding factors (e.g. fear of falling) and use techniques (e.g. TMS, EEG) that can be difficult to perform in free-standing subjects [2].

DESCRIPTION OF THE HANDHOLD MOVER

Our HHM (Figure 1; Table 1) is mounted on a motion-platform, but can be used with any type of balance-perturbation system. A linear-actuator (ball screw and stepper motor) provides accurate control of the handhold motion and end-point locations. The range of motion (800mm) was selected to allow the handhold to move close to the subject when fully-deployed and out of grasping range when fully-retracted. Structural components were designed to withstand the substantial loading that can occur when using a handrail (up to 60% of bodyweight [6]). Ball-bushing rails are used to withstand orthogonal loads, and a brake prevents the motor from being “back-driven” by axial loads. Potential auditory or vibration cues (transmitted through the

1 floor) are minimized by using gradual acceleration/deceleration profiles. Auditory cues can also
2 be masked by playing pre-recorded HHM sounds through headphones. A safety harness
3 restrains subjects from moving into the handhold path-of-motion, and an “interlock” shuts down
4 the HHM if motion-platform force-plates indicate that someone may be standing in its path (Figure
5 2).

6 AN EXAMPLE PROTOCOL

7 To investigate the extent to which peripheral vision can be used to guide balance-recovery
8 reactions, we have programmed the HHM to move intermittently and unpredictably over a 10-30s
9 interval, stopping at one of seven final positions 1-3s before PO (platform translation). During this
10 interval, the subject performs a cognitive task that requires overt visual attention to be directed at
11 a computer screen located directly ahead, at a height that requires
12 head-orientation/gaze-direction similar to that occurring during ambulatory scanning of the travel
13 path [7]. With the subject required to direct gaze at the computer screen, the final locations of the
14 handhold correspond to specific visual angles in the peripheral field (see Figure 1B). Large foam
15 blocks, placed around the feet, prevent stepping and force reliance on reach-to-grasp reactions,
16 which are characterised using motion-analysis and EMG systems. An eye-tracker is used to
17 determine if the subject maintained fixation on the computer screen, or needed to direct gaze at
18 the handhold. For comparative purposes, subjects also perform trials where they maintain visual
19 fixation of the handhold, as it moves.

20 OTHER POTENTIAL APPLICATIONS

21 Many variations of the protocol are possible. For example, contact-lenses could be used
22 to occlude specific regions of the visual field [8], liquid-crystal goggles could be used to occlude
23 vision during specific time intervals of interest [9], and the capacity for on-line control could be
24 probed by programming the handhold to move after initiation of the arm reaction. Potential

- 1 applications range from studies of fundamental motor-control mechanisms to evaluation of clinical
- 2 interventions, such as the “visual-training” programs we are currently studying [10].

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

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Table 1: Technical specifications of the handhold-mover (HHM)

FEATURE		SPECIFICATION	NOTES
Motion	Axis and range of motion	800mm Transverse axis in front of subject, on the right-hand side	Fully-deployed and fully-retracted (out-of-reach) positions are 50mm and 850mm to right of subject's midline, respectively.* Distance between HHM axis and back of heels is equal to 25% of body height.
	End points	Any position within range of motion	Can be specified in absolute position (mm) or in equivalent visual angle (see Fig. 1B)
	Speed	480mm/s (max)	Allows full range of motion to be traversed in 2s; slower speeds can also be programmed. Maximum speed was limited to this value for safety.
	Acceleration/ deceleration	784mm/s (max)	Limited to avoid sudden jerks that could provide vibrational cues (transmitted via motion-platform floor).
Loading limits	Vertical	120kg-f (545N)	60% body weight (see [6]) $\times$ 100kg (95 th percentile male weight) $\times$ 2.0 (safety factor)
	Horizontal	90kg-f (410N)	45% body weight (see [6]) $\times$ 100kg (95 th percentile male weight) $\times$ 2.0 (safety factor) Note: horizontal = parallel or normal to axis of motion
Handhold features *	Height	Adjustable: 915mm - 1120mm	Min: 60% body height $\times$ 1520mm (5 th percentile female) Max: 60% body height $\times$ 1880mm (95 th percentile male)
	Shape	Cylindrical	Cylindrical shape and diameter of 32-44mm are recommended for stair handrails (see [6]).
	Diameter	32mm	
	Length	190mm	95 th percentile male hand breadth = 102mm
	Orientation	Transverse axis	
	Sensors	3 force-sensing resistor strips (FSR-408)	Manufacturer: Interlink Electronics, Inc.; Camarillo, CA. The FSR strips, taped along the length of the handhold (top, back and front surfaces), currently provide contact signals, but could also be calibrated to provide contact-force information. The handhold could be mounted on a multi-axis load cell if more detailed information about the applied forces and moments is required.
Components	Linear actuator	Ball-screw linear-actuator (ROBO cylinder RCP2-SA7)	Manufacturer: Intelligent Actuator Inc.; Torrance, CA Built-in mechanical brake is activated whenever the motor is not running. Handhold position (resolution 0.02mm) is defined by the screw lead (16mm/rev) and stepper-motor encoding (800pulses/rev).
	Linear bushings	4 ball bushings (model SSUPBO12)	Manufacturer: Thomson, Danaher Motion; Washington, DC
	Linear guides	2 parallel 3/4" class-L steel RoundRail	Manufacturer: Thomson, Danaher Motion; Washington, DC
	Structure	Aluminum extrusions (model 15EX1515)	Manufacturer: Faztek LLC; Fort Wayne, IN Extrusions are strong and lightweight; joints are reinforced by steel plates and angle brackets.

*NOTE: The specifications for the HHM axis of motion and handhold features correspond to the prototype system in Figure 1. Other configurations (including the use of multiple HHM's) may be preferred in other studies. It may also be of interest to vary handhold shape, size and/or orientation, e.g. to study the effects on the prehensile phase of the reach-to-grasp reaction.

FIGURE CAPTIONS

Figure 1: Schematic drawings and photographs showing the handhold mover (HHM) mounted on a large ($2m \times 2m$) motion-platform (capable of moving in any horizontal direction), as well as the location of the computer monitor used to provide a visual target (and any other displays required in dual-task studies where the subject performs an ongoing cognitive task): **A.** isometric view; **B.** top view; **C.** photograph of HHM at the fully-retracted (out-of-reach) position ($850mm$ from midline of subject); and **D.** photograph of HHM at the fully-deployed (in-reach) position ($50mm$ from midline); **E.** photograph of a subject grasping the HHM at the fully-deployed position. **B** shows the handhold travel path (black horizontal line), and three end positions that correspond to visual angles of 15° , 25° and 35° (dotted lines) when gaze is directed straight ahead at the computer monitor (visual angle of 0° ; black vertical line).

Figure 2: Flowchart for the custom-written LabVIEW™ program (National Instruments Corp; Austin, TX) used to control the handhold-mover (HHM). The experimenter controls the HHM using a line-by-line text file detailing, for each trial, the pseudorandom sequence of intermittent handhold movements to be completed prior to stopping at the desired final position¹. The text file indicates the end point of each movement (specified as either an absolute position or a visual angle), along with the “dwell time” (i.e. the time to wait before initiating the next handhold movement). The platform motion is triggered, after an optional (random) time delay, once the handhold has completed its sequence of movements. During the interval prior to onset of platform motion, the program monitors the vertical loading of the three force-plates embedded in the motion-platform surface, and aborts the trial (i.e. stops the handhold movement and prevents the triggering of platform motion) if the force-plate signals indicate that the subject (or any other person) may have moved into an area where the moving handhold could strike the body².

Figure 1 **Figure 2**