

A PRELIMINARY STUDY OF GAZE BEHAVIOUR AND UPPER LIMB KINEMATICS IN TRANS-RADIAL USERS

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INTRODUCTION

Tools to evaluate the effectiveness of upper limb prostheses generally measure user's performance on functional tasks or use questionnaires to examine the effect of amputation and prosthesis use on everyday life activities [1]. There have been few studies describing the characteristic changes in motor behaviour associated with learning to use a prosthesis [2, 3]. Such studies potentially provide useful insight into the characteristics that are reflective of skill acquisition and hence may lead to the development of improved outcome measures.

Nevertheless, most of these studies only investigated planar pointing tasks, in which no active involvement of the hand is required and relatively small differences in performance between amputees and anatomically intact controls were observed. In contrast, previous studies of activities of daily living (ADL) performance have shown clear differences in joint kinematics and task completion time between healthy subjects and amputees [4]. Moreover, despite the widespread agreement regarding the role of the vision in prosthetic use [3, 5-8], and the extensive literature on the role of vision in learning to use a tool (e.g. [9, 10]) and in the performance of ADLs [11], gaze behaviour in upper limb prosthesis users has received limited attention [3].

In this study, we evaluated the changes to kinematics and gaze behaviour associated with learning to use a myoelectric prosthesis for the performance of an ADL task. We chose to study anatomically intact subjects to allow for comparison of task performance with the prosthesis against performance using the anatomical upper limb. The study firstly aimed to describe characteristic factors which differentiate upper limb task performance with the anatomical hand from performance with a myoelectric prosthesis. The second aim was to identify those factors which changed with skill acquisition while learning to use the prosthesis. Due to space limitations, in this paper we describe the methods and present detailed results from the gaze behaviour part of the study. However, a full set of results, including the kinematics, will be presented at the conference.

METHODS

The study was approved by the University of Salford Research Ethics committee. Following written consent, five anatomically intact, right-handed individuals, (3 males and 2 females) with a mean age of 30 years (ranged from 26-41) were recruited. All subjects were in good physical condition and had within-normal visual acuity. All data were gathered in the Movement Science Laboratory at the University of Salford, Salford, UK.

The experimental setup is discussed in more detail in [12] and hence only brief details are provided here. The study was a cross-over design (Table 1). Participants' gaze behaviour and upper limb kinematics during the performance of an ADL task were evaluated twice in separate sessions (E1 and E2) which formed a baseline phase. Following this they were fitted with a myoelectric prosthesis simulator (see [12]). Subjects were then evaluated 3 further times over the course of approximately 2 weeks, when performing the task with their prosthesis (E3-E5). We also provided 6 separate practice sessions (P). During each of these sessions, subjects performed the Southampton Hand Assessment Procedure (SHAP) once [13]. The SHAP sessions were performed on different days to the evaluation sessions, to avoid fatigue. The SHAP test not only provided an opportunity for participants to practice, but also allowed for an evaluation of hand function over the course of the study.

The ADL task carried out in each of the evaluation (E) sessions involved reaching for a carton and pouring water from the carton into a glass, then replacing the carton on to the table. The task was challenging to perform with the prosthesis and had a cost (water spillage) associated with poor performance. At each evaluation session (E) subjects repeated the task 12 times and the first 10 repeats in which good data were collected were considered for analysis. At the start of each evaluation session the subject was seated upright in a chair with his/her back resting on the chair back, the upper arm in a neutral position and both hands resting comfortably on the table. The location of the hands when rested on the table were then marked (termed reference positions) to serve as the start points for each

repetition of the task. At the start of each attempt to complete the task, the subject was instructed to initiate the movement from the reference position and to return to the reference position at the end.

Table 1: Experimental protocol

	Phases	Events	Data collection
0 ~2 weeks	Baseline phase (Anatomical hand)	E1: Task performance (12 repeats)	Kinematics Gaze
		P1: Practice session	Hand functionality
		E2: Task performance (12 repeats)	Kinematics Gaze
		P2: Practice session	Hand functionality
	Training phase (Prosthesis)	E3: Task Performance (12 repeats)	Kinematics Gaze
		P3: Practice session	Hand functionality
		P4: Practice session	Hand functionality
		E4: Task performance (12 repeats)	Kinematics Gaze
		P5: Practice session	Hand functionality
		P6: Practice session	Hand functionality
		E5: Task performance (12 repeats)	Kinematics Gaze

Prior to starting each attempt at the task, the subject was instructed to gaze at a marked point (termed the gaze reference point or GRP) placed in the middle of the table. The GRP was a visual start and end point for all subjects throughout the testing. During task completion, subjects were free to move their eyes as they wish. Furthermore, no constraint on head movement was applied during the task performance. At the end of task completion, the subject was instructed to return their gaze to the GRP. When the prosthesis was used, the table was moved forward relative to the chair to accommodate the extra-length of the prosthesis.

Kinematics instrumentation

Kinematic data were calculated from the positions of reflective markers located on the subject's upper body, collected using the Vicon 612[®] motion capture system (Vicon Motion Systems, Los Angeles, USA) (Figure 1). Marker positions were sampled at 100 Hz. Further details on the analysis and results from this part of the study will be presented at the conference.

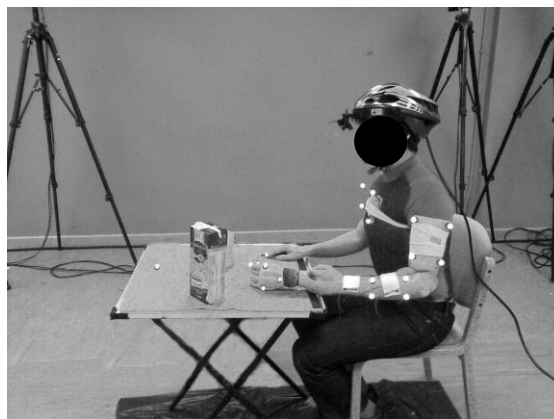


Figure 1: Experimental setup

Gaze data

Gaze data while performing the task were captured using a head-mounted Eye-Tracking system, iView X[™] HED 2 (SenseMotoric Instruments GmbH, Tellow, Germany). This system is a head-mounted tool, which continuously tracks the movement of the pupil and projects the location of gaze in a scene video, collected from a head-mounted camera, thus allowing the overlay of gaze position on the scene video to be invariant of head movements. The method for gaze data analysis has been discussed elsewhere in the conference proceedings [12]. In summary, we divided the scene ahead into discrete areas of interest (AOIs) that allowed the pattern of gaze fixations to be described. In each recorded trial, and for each phase, the duration of fixations at each of the AOIs were identified and normalised by the phase duration. For each subject and for each of testing session, the normalised fixation durations of each of AOIs and that for all coded trials in each phase were summed and averaged by the number of trials ($n= 10$). Then for each of testing sessions, an average of the normalised averaged fixation duration was calculated for all subjects

Functionality scores

The SHAP test produces a functionality profile, based on the time taken to complete each of the 26 tasks [13]. From this profile, an overall functionality score is calculated, using the web-based software produced by the developers of the evaluation tool (<http://www.shap.ecs.soton.ac.uk/entry.php>).

RESULTS

In all the graphs, for ease of interpretation, and where appropriate, a dashed line is used to separate anatomical hand's data from prosthetic hand data. Error bar indicates 1 standard deviation (STD) in all cases.

Hand function (SHAP) scores and task completion time

Table 2 shows the mean SHAP scores of all subjects gathered during the practice sessions and time to complete

the manual tasks (pouring water from a carton into a glass) across the evaluation sessions.

Table 2: Mean (STD) SHAP scores in practice sessions (P) and time to complete the manual task across evaluation sessions (E).

SHAP	E1	P1	E2	P2	E3	P3	P4	E4	P5	P6	E5
SHAP		94 (1)		96.4 (2.1)		36.8 (6.7)	51 (3.3)		60 (6.4)	67.4 (4.5)	
Task duration	11.2 (2.8)		10.2 (1.8)		17.6 (2.7)			16.0 (2.1)			14.8 (1.6)

Gaze data

In this paper we only present gaze data from sessions E1, E3 and E5. The normalised average total fixation durations at every AOI for all subjects across the key sessions (E1, E3 and E5) are illustrated in figure 2.

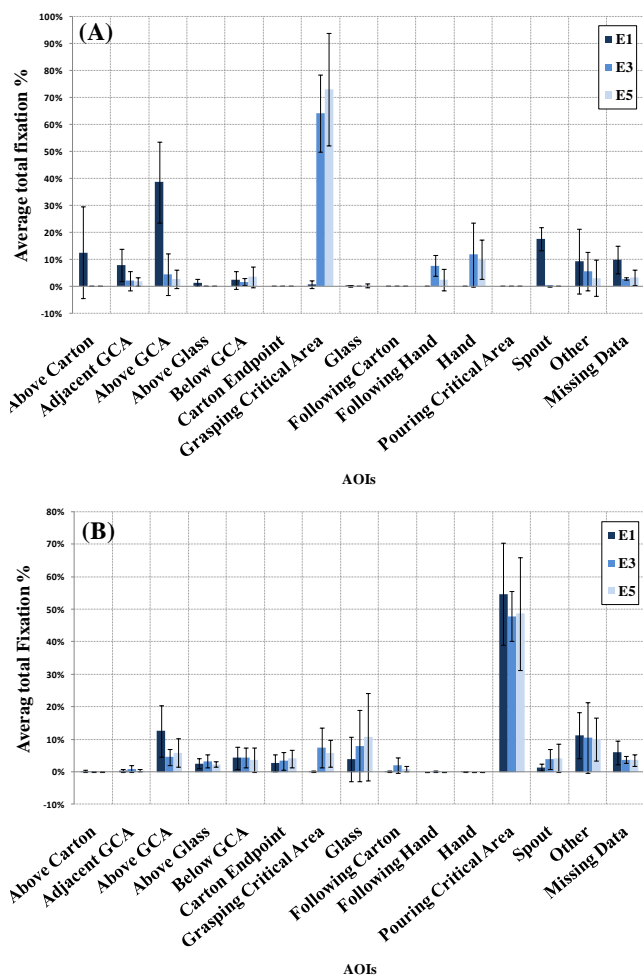


Figure 2: The normalised average total fixation duration at AOIs across sessions E1, E3 and E5 for all subjects, (A) during reaching phase and (B) during manipulation.

DISCUSSION

SHAP and task completion time

The results of the SHAP tests indicate a clear effect of the introduction of the prosthesis on functionality. SHAP scores declined dramatically from around 95 in the baseline (session P1 and P2) to 36 on the first session with a prosthesis (session P3). The effect of practice is evident by the steady increase in SHAP scores with time.

Time to complete the manual task in the evaluation sessions also increased significantly on introducing the prosthesis (Table 2). However with practice, and in keeping with SHAP results, a steady decrease in time to complete the task was observed.

Gaze data

With regard to the gaze results, for ease of discussion, we will focus only on the small number of AOIs that either showed major changes in the duration of fixation between baseline and session E3, or showed significant changes with training (large difference between E3 and E5).

Reaching phase

As can be seen in Figure 2A, there were major and relatively invariant differences in gaze behaviour between anatomical and prosthetic reaching. In line with previous research [11], during reaching with the anatomical hand subjects did not generally focus either on the hand or its associated AOI (following the hand). Instead, while reaching subjects tended to fixate their gaze mostly at the areas of relevance to the subsequent action (look ahead fixations [14]) (68% of total fixation), notably at "Above Grasp Critical Area", "Spout" and/or "Above Carton" which allows planning to the action ahead in time.

In stark contrast to reaching with the anatomical hand, prosthetic reaching was mostly initiated with gaze fixation at the "Grasping Critical Area" (GCA) (64% of fixations) and, in some subjects, occasional fixation at the prosthetic hand (Figure 2A). While reaching, subjects most often pursued the prosthetic hand and/or flickered between the Hand and GCA. The attendance to the GCA may indicate concern with the hand-carton interaction aiming to correctly and securely grip the carton. Attention at the "Hand", and "Following Hand" AOIs may be associated with concern regarding the hand configuration and location. Attention to these areas (GCA, Hand, and Following Hand) largely precluded the subjects from planning for the manipulation phase.

It appeared that with practice, the duration of the fixation at GCA during reaching to grasp increased slightly, probably as a result of a shorter fixation on the hand area. Such a change in the gaze behaviour may reflect the ability the

subjects to incorporate the prosthesis in the internal model of the arm.

Manipulation phase

In contrast to the reaching phase, changes in gaze behaviour during the manipulation phase between baseline and prosthetic sessions were not as clearly differentiated (Figure 2B). Nevertheless, unlike when using the anatomical hand, using the prosthesis required noticeable attention to the GCA during the manipulation phase (8% of total fixation). This may reflect the lack of the reliable feedback from prosthesis regarding the hand state.

While using the prosthesis, it is noticeable that subjects fixated more on the "Glass" (from 7% to 11% of total fixation) and less at Pouring Critical Area (from 55% to 48%) which is probably due to the poor sensory feedback via the prosthesis to estimate the remaining amount of water in the carton.

CONCLUSIONS

Despite the dramatic improvement in prosthetic technology, the extent to which amputees make use of their prosthesis in everyday life to perform functional tasks still appears to be low. This study has shown that gaze behaviours clearly change when compared with those during performance of an everyday task with the anatomical limb. Smaller, but still noticeable changes in gaze behaviour were observed with learning to use the prosthesis. A future study in an upper limb amputee population will investigate whether this characteristic may help to explain observed differences in prosthetic usage.

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