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CODING SCHEME FOR CHARACTERISING GAZE BEHAVIOUR OF PROSTHETIC USE

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INTRODUCTION

During the performance of a task in which detailed visual information is central to its success the centre of the visual field (located at the fovea) is continuously focused on key visual cues within the scene [1]. Studies suggest that the visual behaviour during the performance of a novel and challenging upper limb task changes as subjects become skilled[1] [3]. For example, during the early stages of learning to use a hand-operated tool, gaze closely monitors the tool movement towards the target, to obtain visual feedback on its location. With training, the relationships between arm movements and tool location are established and thus tool location can be predicted from proprioceptive feedback. This leads to a change in gaze behaviour, with fixation increasingly moving to the target, rather than following the tool.

The changes to gaze behaviour over the course of skill acquisition have a number of potential clinical applications. For example, comparing gaze behaviour of trainees with gaze behaviour of experts may provide useful insight into trainees' performance [4]. Gaze might also be used as a training tool in itself. For example, a study of novice basketball players showed that improvements in performance resulted from observing gaze behaviours of expert players [5].

In studies of gaze behaviour, the location of the foveal focus is typically estimated from data collected from a head-mounted camera monitoring the eye. These data are used to project a symbol (typically a cross-hair) onto a scene video, which is collected from a second head-mounted camera. In order to interpret gaze data a method is required for describing and summarizing the trajectory of the foveal gaze within the scene video.

In previous work on gaze behaviour in the performance of everyday tasks (i.e. in unstructured environments), gaze has been described in terms of periods spent focusing on Areas of Interest (AOI). Areas of Interests (AOIs) in the scene video typically consisted of a set of objects that the eye was focused on during the task performance. Although more recent work has begun to consider the functional implications of focusing on different parts of objects, there are very few examples in the literature of clearly described coding schemes that allow for such behaviour to be unambiguously described. Describing gaze data without a predefined coding scheme is likely to make the process open to personal interpretation of the rater.

The gaze location is projected on to a 2D video of the scene containing no information about the depth. This discrepancy in the dimensionality might make also the gaze location open to misinterpretation and hence poor inter-rater reliability. For instance, if two AOIs overlap with each other in the line of sight, a common occurrence in manual tasks, the cursor would be projected on to the object that is closer to the subject. However, there is ambiguity in some cases. For example, in cases where gaze is focused on one object and, a second object is moved to partly obscure vision of the first object, it is difficult to judge whether the subject is taking information from the near, or far object.

In a related paper [6], we report on a study of gaze behaviour during the performance of a functional task (pouring water from a carton to a cup) in anatomically intact subjects learning to control a myoelectric prosthesis. In this paper we describe the development and validation of an objective gaze coding scheme for characterization of gaze behaviour during performance of the carton pouring task By describing the process by which the scheme was developed we provide the potential to generalise the approach to other similar tasks. AOIs in the scene are strictly defined, based on a functional interpretation. A method is proposed for dealing with uncertainty in AOIs arising from the dimensionality discrepancy between the 3D scene and 2D gaze video data. Finally, we report an inter-rater reliability study demonstrating the reliability of the proposed coding scheme.

[1] We define skilled motor behaviour as the ability to predict the consequences of physical actions [2]

METHODS

Subjects

Following ethical approval from the University of Salford's Research Ethics Committee, 2 right-handed anatomically intact male subjects (28 and 30 years) who had normal-to-corrected acuity and colour vision were recruited for this study. Prior to admission to the study, all subjects signed an informed consent form.

Manual task performance and gaze tracking

Gaze data were gathered using the iView X™ HED 2 (SenseMotoric Instruments GmbH, Tellow, Germany) Eye-Tracking system.

The subjects sat with their back straight, supported by the back rest of a chair, with both upper arms abducted by approximately 30º, elbows in about 90º flexion and with hands resting comfortably on top of the table (Figure 1). The subject was asked to complete a well-defined, everyday functional task "pouring liquid from a carton into a glass" using their left hand (non-dominant hand)[2]. The carton was placed at a location that could be comfortably reached by the subject, without leaning forward. This location was marked for use in subsequent trials.

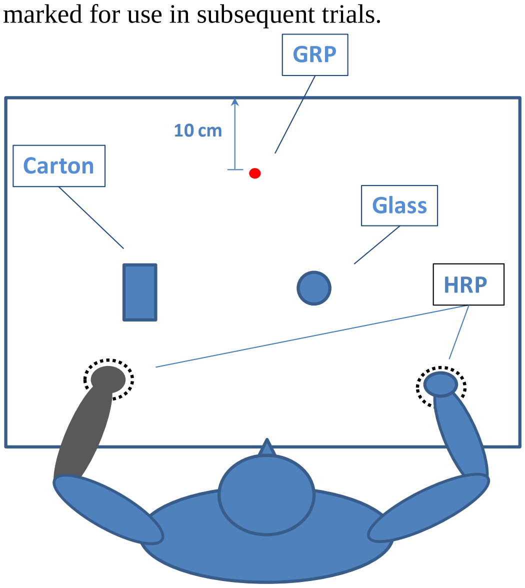

Figure 1: Experimental setup

Subjects were instructed to initiate the task from the hand reference points (HRP, Figure 1) and to return to the reference points at the end. The subjects first reached for the carton, then grasped it, transported it towards the glass, poured a fixed volume of water from the carton into the glass, returned it to its original location, then released the carton and returned the hands to their original positions. This task requires the subject to pay visual attention in order to not spill the water. Further, the carton was easily deformable, potentially adding to the task difficulty.

Subjects were instructed to gaze at a marked point (termed the gaze reference point or GRP) prior to initiating the task and at the end of the task (Figure 1). During task completion, subjects were free to move their eyes as they wished. Furthermore, no constraint on head movement was applied during the task performance.

Data collection was completed over two separate testing sessions approximately 3 days apart; in the first session the task was performed using their left arm; in the second session subjects used a myoelectric prosthesis, fitted over their left arm (Figure 2) to complete the task. The myoelectric prosthesis was equipped with a single degree of freedom electrical hand (RSLSteeper "Select" Myo Electric hand (size 81/4)), whose opening and closing was controlled via EMG signals from a socket-located electrode (for more detail see [7]). In each session, subjects completed the manual task as described above 10 times. Subjects were instructed to perform the task at their own pace. Prior to the second session, the table was moved away from the chair by a suitable distance to accommodate the extra-length of the prosthesis.

Development of the coding scheme

In gaze analysis the scene ahead is typically subdivided into discrete areas of interest (AOIs). Most of the researchers who have studied the performance of functional tasks have defined the set of AOIs as being the set of objects in the scene (see Land et al [1, 8], Hayhoe [9]). Preliminary analysis of our data from the first session showed similar trends to those reported by Land, Hayhoe and others ([1, 8], Hayhoe [9]) with a characteristic sequential pattern of fixation on objects, which could be assumed to contain the necessary visual cue to perform the task [10]. However, close inspection of the gaze data shows that the fixation occurred at specific areas on the objects that appear to have particular functional importance. This fixation on specific areas of objects was also observed in a study by Johansson et al [11] and in our earlier pilot work [10]. Thus, certain areas on the objects seem to be of more importance to the completion of the task than the rest of the object. This suggests that coding schemes that consider only the focus on a particular object as a single unit may be losing useful information.

Therefore it was decided to divide the area that an object occupies into a number of AOIs. The set of AOIs was determined following a series of discussions following pilot data collection, based on the assumption that AOIs should have functional relevance. In addition, three further AOI's were defined that were not part of an object, but functionally related to the nearby object: eye "Following the hand", eye "Following the carton" and Above Carton. These AOIs

[2] The study was limited by the availability of only left-handed myoelectric hands within the Department

A total of 14 AOIs were identified, as well as a "missing data" category (to account for saccades, blinks and periods when gaze location was undefined), as shown in Figure 2.

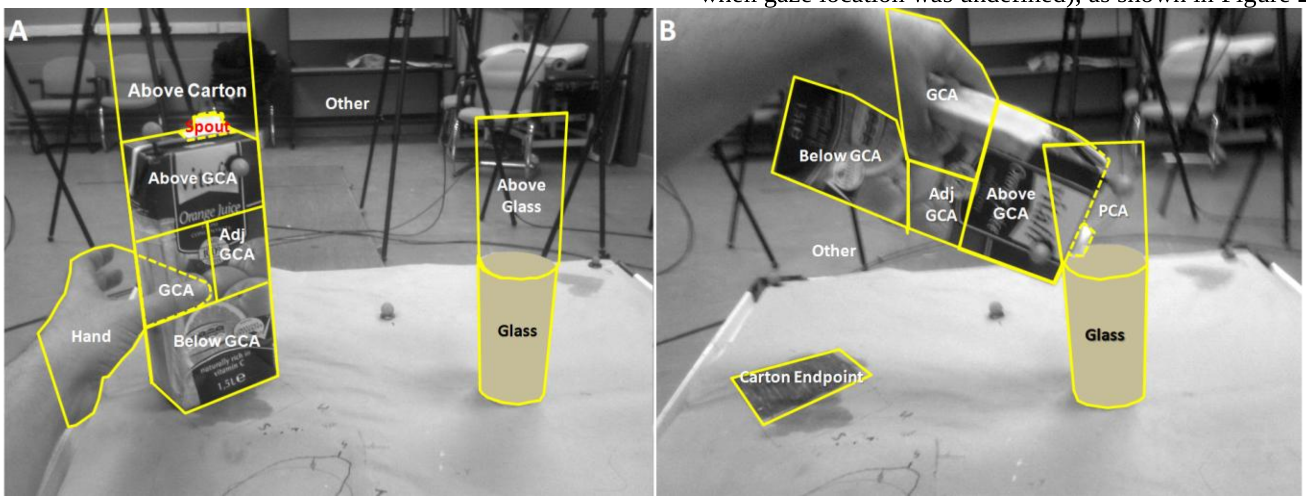

Figure 2: The areas of interest (AOIs). Note – "Following Hand" and "Following Carton" are not shown.

Due to space limitations, it is not possible to describe each AOI and its derivation in detail. However, it is worth highlighting two functional areas: Grasping Critical Area (GCA) is the area on the carton at which the hand makes contact. This definition accounts for between trials and between subjects variations. When the carton is grasped by the hand, the GCA extends to include "Hand" AOI, as the functional purpose of both AOIs may be assumed to be the same. Pouring Critical Area (PCA) is not a subset of an object AOI, but rather a functional area that emerges during the pouring action.

To reduce ambiguity in the interpretation of the video, a confusion matrix showing all possible interactions between AOIs was developed. In the event of two AOIs overlapping, one of the AOIs is prioritised.

CODING SCHEME INTER-RATER RELIABILITY

Following the development of the coding scheme, the data from the two subjects were coded using BeGaze software (SensoMotoric Instruments GmbH, Tellow, Germany) that comprises a built-in algorithm to discriminate fixation periods from other periods (saccades and blinks). Two raters (M and R) were invited to separately code gaze data for both subjects. Each rater was asked to firstly define the onset and the end of the task based on the hand movement and then to record the temporal sequence of gaze on AOIs, as well as the time spent on each AOI. The mean task duration is listed in Table 1 for the two raters. A t-test showed no significant difference in task duration between raters (*p-value* = 0.684).

Table 1: Mean (SD) of task completion duration in seconds as measured by the two raters.

Subject (condition)	Rater M	Rater S
Subject 1 (anatomical hand)	10.1 (0.9)	10.3 (1)
Subject 1 (Prosthesis)	18.2 (2.5)	19.1 (3.4)
Subject 2 (anatomical hand)	10.5 (1.1)	10.4 (0.9)
Subject 2 (prosthesis)	18.9 (3.6)	18.6 (3.8)

Figure 2 shows examples of the gaze sequence and normalized fixation duration of subjects 1 and 2 using the anatomical hand, and the prosthesis, as coded by each rater.

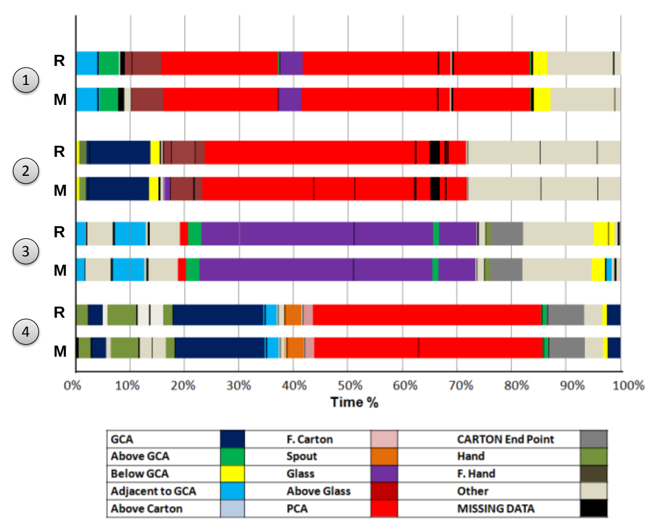

Figure 3: Examples of gaze sequence as coded by raters M and R: (1) subject 1 anatomical hand, (2) subject 1

prosthesis, (3) subject 2 anatomical hand, (4) subject 2 prosthesis.

Table 2 gives the total gaze duration at each AOI (the sum of total fixation duration) and frequency of fixation at each AOI for each rater for all trials.

The interclass correlation coefficient (ICC) was used to compare the total fixation duration at each AOI for each coded trial between the two raters. The 2-way random absolute agreement between the raters was highly comparable as revealed by the ICC (ICC = 0.975, p-value <0.001), with high internal consistency (Cronbach's alpha coefficient = 0.987).

Table 2: Total gaze duration and frequency of gaze fixation at each AOI.

AOI \ Rater	Total Gaze Duration [s]		Frequency	
	M	R	M	R
Grasping Critical Area (GCA)	37.2	38.1	45	50
Above GCA	21.9	21.7	66	68
Below GCA	5.1	5.3	31	29
Adj GCA	3.6	3.8	17	18
F Carton	0.3	0.3	1	1
Spout	7.2	7.2	37	36
Glass	21.2	18.2	43	43
Above Glass	8.1	10.9	56	59
Pouring Critical Area	101.9	106.6	36	37
Carton Endpoint	7.1	8.8	23	19
Hand	12.7	11.2	24	18
F Hand	1.9	1.9	54	48
Above Carton	0	0	0	0
Other	51.0	47.2	154	138
Missing Data	15.7	16.2	253	262

DISCUSSION

Eye tracking offers an object method to explore visual attention. However, gaze coding is usually carried out by visual inspection of the data, sample by sample, and judging which AOI is being hit. The coding scheme therefore was developed to address the subjectivity that the coding process entails.

Interestingly, the distribution of focus on such areas appears to change when the prosthesis arm is introduced [10]. Therefore, a coding scheme that simply considered objects as the AOIs, would fail to account for the observed changes in fixation patterns.

Nevertheless and despite the effort to eliminate the subjectivity of gaze coding, in a few cases location of the gaze fixation was observed to still depend on the rater's opinion. For instance, when the gaze is fixating marginally between adjacent AOIs, the rater has to decide which AOI to consider. Furthermore, the confusion matrix might not be fully optimized for this task. However any misinterpretation should be consistent and hence can be seen as a source of systematic error.

As the main interest of the reliability investigation is to explore the agreement of the raters to code gaze under the testing conditions, gaze data of both subjects were treated as one sample of independent variables that was rated by two independent raters.
These results demonstrate the reliability of the coding scheme.

CONCLUSIONS

A coding scheme with function-related AOIs has been developed. This study reports, to our knowledge, the first attempt to produce a detailed and reliable coding scheme that incorporate sub-parts of objects as AOIs defined by function, and this is likely to be of interest to researchers studying gaze during complex motor activities. Although defined AOIs might be exclusively applicable to our task, the method used to define AOIs in this work can be generalized.

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