Visuomotor Behaviour of Upper Limb Prosthesis Users: Protocol for a Scoping Review

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Introduction

An upper limb amputation is a major life-altering event that involves the absence or removal of any part of the fingers, hand, or arm. Upper limb loss can occur due to a congenital deficiency, or can result from trauma, infection, vascular disease or malignancy. In the United States, there were an estimated 1.6 million people living with a limb loss in 2005; 41,000 of which had a major upper limb amputation[1]. By 2050, the total number of Americans with a limb loss is projected to double to 3.6 million people[1]. Although the prevalence of upper limb loss is less than that of lower limb loss, the loss of the fine motor skills of the hand has been reported to have devastating effects on an individual's life [2]. The hand is highly skilled in fine motor control and provides a means of interacting with objects in everyday life. Seemingly simple manipulations of the hand, such as reaching and grasping for an object, involves the complex coordination of multiple joints in the hand and arm[3]. Even the most sophisticated robotic arms cannot fully replicate the dexterity of the human hand.

Recent technological and surgical advances have attempted to restore the highly dexterous and complex capacities of the human hand. Beyond simple cable-driven body-powered prostheses, myoelectric prostheses and targeted muscle reinnervation have aimed to improve the functionality of robotic arms. Myoelectric-controlled prostheses utilize the intrinsic muscle signals of the residual limb and can typically be controlled via a direct control method (using signals from antagonistic muscles) or pattern recognition[4]. Conventional direct control is simple, but requires a switching strategy to control other joint movements[4]. This control method is also susceptible to crosstalk, muscle co-contractions, and contribution from deep muscles, which has driven the developments in pattern recognition for myoelectric prostheses[4]. Pattern recognition has the capacity to provide users with natural and intuitive control in multiple degrees of freedom. However, it is not without its challenges, as the daily use of a prosthetic device introduces variation in electrode placement, force of contractions, and limb position, which may contribute to unintended movements of the prosthesis[4]. Furthermore, with higher levels of limb loss, there are fewer physiologically appropriate muscles sites for use with pattern recognition[4]. Targeted muscle reinnervation is a novel surgical technique that transfers residual nerves from the amputated limb to a new target muscle[4]. Neural information from the distal limb, such as the hand and wrist can be restored at a more proximal target muscle site[4]. In combination with pattern recognition, this method can effectively discriminate multiple classes of movements[4]. Despite the potential for prosthetic advancements to greatly improve motor function, the assessment tools necessary to evaluate user functionality of these devices are limited in their ability to detect changes in prosthetic control.

The majority of outcome performance measures available to evaluate the function of upper limb prosthesis users are reliant on the rater's skill. Few outcome measures have been standardized for use specifically in an upper limb amputation population[5]. Common assessments include the Assessment of Capacity for Myoelectric Control (ACMC), Activities Measure for Upper Limb Amputees (AMULA) and the Southampton Hand Assessment Procedure (SHAP), which rely on observer ratings or task completion time. Current performance measures adequately assess upper limb function of prosthesis users, however, these measures do not address the visuomotor behaviours. The ability to assess the way in which individuals integrate a prosthetic device into their movement patterns can be achieved using motion capture and eye tracking.

More recent research employs the use of technology to quantitatively assess the function of upper limb prostheses. Specifically, the use of synchronized motion capture and eye tracking is a technique that allows for eye behaviour to be assessed during object interaction[6]. Motion capture provides quantitative measurement of hand and upper body movements, while eye tracking quantifies eye movement in relation to the environment. Eye metrics collected using this technology can provide insights into movement planning. Additionally, voluntary eye movements directed to a target in space correspond to a shift in the allocation of cognitive attention[7]. The interconnected relation of eye and hand movements in an able-bodied population has been widely studied and is well-documented[8], and normative eye tracking metrics are well-characterized[9]. Various research groups have employed the use of motion capture and eye tracking to evaluate prosthesis function, however variability in their methodologies exists. Due to varying functional task demands and different methods of synthesizing the data, it is difficult to compare results across research groups. The visuomotor behaviour of upper limb prosthesis users may provide insight into motor planning and cognitive behaviour, and there is increasing interest in this area of study. A scoping review would serve to summarize previously observed visuomotor behaviours of upper limb prosthesis users. A brief search of the literature has not revealed any literature reviews in this topic to date.

The overall goal of this scoping review is to provide an understanding of the visuomotor behaviour of upper limb prosthesis users. The visual patterns exhibited by these individuals during reach-and-grasp tasks could provide insights into human behaviour. This scoping review will provide clinicians and researchers with a better understanding of the way in which individuals with upper limb amputation interact with their prosthetic device, how vision is used in motor planning, and the cognitive demand associated with controlling a prosthetic device.

The specific aims of this scoping review are: 1) to characterize the visuomotor behaviour of upper limb prosthesis users reported in research studies that have utilized motion capture and eye tracking technology, 2) to summarize the eye tracking metrics and variables commonly used to describe visual attention when manipulating a prosthetic hand, and 3) to identify gaps in the literature and potential areas for future research. This scoping review will follow the PRISMA-ScR statement and checklist[10].

Inclusion Criteria

Population

This scoping review will include research participants of all ages with an upper limb amputation who use a body-powered or myoelectric prosthetic device. The population will also include able-bodied research participants who perform tasks using a simulated prosthetic hand. These simulated devices can include a robotic hand attached to the forearm via a brace, the control of a simulated hand in virtual reality, or other simulated prosthetic devices.

Concept

The concept of this scoping review will focus on the visuomotor behaviour of upper limb prosthesis users when reaching for and grasping an object. In addition, this scoping review will explore the eye metrics used to evaluate visuomotor behaviours of prosthesis users. Eye metrics such as eye arrival and leaving latencies, percentage of visual fixations, and number of visual fixations will be examined to understand the visuomotor behaviour of these individuals. Other eye metrics, such as pupil diameter that have been reported in the literature will also be considered in this scoping review.

Context

Literature from a wide context will be included in this scoping review. The context will not be limited by geographic location, social status, or culture.

Methods

Search Strategy

Primary research articles and reviews will be considered in this scoping review, as well as grey literature, such as conference papers and dissertations. Opinion articles and non peer-reviewed journals however will not be included. The search will not be limited by language. If a non-English article is included in the title and abstract screening, the authors will be contacted to inquire about an English translation. If necessary, the authors of primary research articles and reviews may be contacted for further information.

The search strategy will be developed by two reviewers (KC and MR) and will follow three general steps. First, a preliminary search of two databases (MEDLINE and EMBASE) will be performed to explore the literature available on this topic. Key words will be identified from the titles and abstracts of these initial papers, as well as the index terms used to describe these articles. Next, these key words and index terms will be used to perform focussed searches in each database. Given the specificity of the population and concept being searched as part of this scoping review, this search strategy was deemed optimal. Search strategies will vary slightly for each database and will be modified accordingly. The databases that will be searched include: MEDLINE, EMBASE, PsycINFO, SCOPUS, ProQuest Dissertations, and Google Scholar. Finally, the reference lists of articles selected for full-text review will be searched for additional sources.

A complete search strategy for MEDLINE is included in the appendix of this protocol. The search will be limited by the end date on which the search was conducted. All literature included in the search will be published on or before the date of the search. A PRISMA flowchart that details the review process from search to source selection, duplicates, full-text retrieval, additions from any third search, data extraction and presentation of the evidence will be included.

Selection Process

The final search results will be uploaded to Covidence where de-duplication will occur[11]. The selection of articles will be based on the inclusion criteria stated in this protocol. Two independent reviewers (KC and MR) will perform an initial title and abstract screening of the results. If there are any disagreements at this stage, the article will continue to the next stage for a full-text review to decide on its inclusion. Full-text reviews will then be completed independently by the same reviewers (KC and MR) for the final decision on inclusion or exclusion of the paper. If a consensus cannot be reached, the decision will fall to a third reviewer (JH).

Data extraction

The data will be extracted from research articles to provide a descriptive summary of the results that aligns with the objectives of this scoping review. Key information will include the authors, the year of publication, the aims/purpose of the study, participant information (number, age range, sex ratio, type of prosthesis, experience with prosthesis), experimental design, data collection methods, eye tracking measures, and key findings that relate to the scoping review question.

Data will be extracted into a chart and this charting tool will be revised and updated as necessary if it becomes apparent that additional data should be included for the purposes of this scoping review. First, the data extraction process will be piloted by two reviewers (KC and MR) for at least two selected articles to ensure that all relevant information is extracted. Following this pilot stage, the data from the remainder of the articles will be extracted by one reviewer (KC).

Summary of Evidence

Once the data has been extracted from the included articles, the data will be collated into relevant conceptual categories that explain the visuomotor behaviour of prosthesis users. Simple frequency counts of participant characteristics, types of methodology, and general findings will be included in the analysis. Similarities and differences in reported results will be explored and discussed.

Presentation of Results

The results will be presented in a tabular form and will be categorized by conceptual categories that include context, type of prosthesis, study aims, types of methodology, key findings, and gaps in the research. A descriptive summary will accompany the tabulated results and will serve to answer the review objectives and question. Altogether, these results will aim to identify, characterize, and summarize research evidence, as well as identify research gaps.

References

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Appendix 1

MEDLINE (49 results)

1. (exp Artificial Limbs/ or bone-anchored prosthesis/ or implants, experimental/ or prosthesis design/ or (prosthe* or artificial).mp.) and (upper extremity/ or wrist/ or exp hand/ or elbow/ or shoulder/)

2. ((prosthe* or artificial) adj3 (upper extremit* or "upper limb*" or hand or hands or wrist* or arm or arms or elbow or elbows or "humer* or transhumer*" or "trans-humer*" or "transradia*" or "trans-radia*")).mp.

3. exp Artificial Limbs/ and ("upper extremit*" or "upper limb*" or hand or hands or wrist* or arm or arms or elbow or elbows or "humer* or transhumer*" or "trans-humer*" or "transradia*" or "trans-radia*").mp.

4. (amput* adj2 (above elbow* or below elbow*)).mp.

5. 1 or 2 or 3 or 4

6. exp Fixation, Ocular/

7. exp Eye-Tracking Technology/

8. (visuomotor or visuo-motor or ((visuomotor or visuo-motor) adj2 (control or strategy or attention or coordination))).mp.

9. (visualmotor or visual-motor or ((visualmotor or visual-motor) adj2 (control or strategy or attention or coordination))).mp.

10. (visual adj2 (fixation or attention or coordination)).mp.

11. (gaze adj2 (track or tracking or behaviour or behavior)).mp.

12. (eye-hand coordination or eye tracking or eye-tracking).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

13. 6 or 7 or 8 or 9 or 10 or 11 or 12

14. 5 and 13

15. limit 14 to animals

16. 14 not 15