TECHNOLOGY TO MONITOR EVERYDAY UPPER-LIMB PROSTHESIS USE – A REVIEW

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ABSTRACT

Real-world monitoring offers an objective way of exploring the everyday wear and use of upper-limb prostheses. To inform future developments in this field, a systematic literature review was undertaken, highlighting studies that monitored the activity of prosthesis-users during daily-living. Nine papers relating to the upper-limb were identified, and sixty relating to the lower-limb. Here we concentrate on the ways in which technologies have been utilised to assess the use of upper-limb prosthesis, whilst also drawing on the findings of the broader review to highlight potential uses of these measures, alongside the benefits and disadvantages of different approaches.

INTRODUCTION

If the benefits associated with wearing a prosthesis are outweighed by the drawbacks, then a person may choose not to wear or use it [1,2]. Additional complexity, weight and cost associated with prosthetic prehensile function is only of sufficient value if it is used in everyday life. Clearly, these issues around wear and use are context (e.g. time/setting) specific and may vary person to person. However, until recently, the primary methods of determining how upper-limb prostheses were worn and used on a day-to-day basis was through self-report and examination of the prosthesis (e.g. a worn-out cosmetic glove or mechanism). Over the past 5-6 years, researchers have begun to use technology (e.g. sensors on, or in the prosthesis) to objectively assess upper-limb prosthesis wear and use once the person leaves the clinic.

Although monitoring of real-world wear and use is a relatively new approach to upper-limb assessment, the first papers reporting activity monitoring in people with lower-limb absence were published in the 1990's. By understanding how researchers have used real world monitoring to assess lower-limb prosthesis users, as well as the relative merits of the different approaches, it may be possible to guide the development of appropriate approaches to the evaluation of upper-limb outcome measures.

Here we present the results of a literature review which explored the ways in which technology has been used to monitor everyday prosthesis use. The findings of studies using real world monitoring techniques in upper limb applications will be presented, together with potential lessons to be learnt from the lower-limb field. Finally, conclusions will be drawn as to future work.

METHODOLOGY

Five databases (MedLine, Web of Science, Scopus, CINAHL and EMBASE) were systematically searched to identify all papers published up to 1st November 2019. The search employed three groups of keywords as detailed in Figure 1.

Real-world activity:

"daily living" OR "free living" OR "daily life" OR "real world" OR activit* OR mobility OR "prosthetic use" OR "home use" OR "real life" OR "daily use"

AND

Population of interest:

"artificial limb" OR "artificial leg" OR "artificial arm" OR (prosthe* OR amput* AND (limb OR leg OR arm OR hand OR wrist OR elbow OR foot OR ankle OR knee OR transradial OR trans-radial OR transhumeral OR trans-humeral OR transtibial OR trans-tibial OR transfemoral OR trans-femoral))

AND

Sensor for monitoring activity:

actimetry OR sensor OR monitor* OR "inertial measurement unit" OR IMU OR acceleromet* OR gyroscope OR magnetometer OR "global positioning system" OR GPS OR "step count" OR pedometer OR "cadence" OR "steps/" OR "steps per"

Figure 1: Search terms employed to identify all studies that monitored the activity of prosthesis-users during daily-living.

Only papers which reported first-hand on sensor-based monitoring of people with prostheses in a community setting (i.e. outside the lab or clinic) were included in the final review. For all included papers, reference lists and forward citation reports from each database were consulted in order to identify additional relevant articles that were not found in the automatic search.

RESULTS

The search returned 2793 papers across the 5 databases. After removing duplicates, 1716 were screened by title and abstract; of these, five papers relating to the upper-limb were identified as relevant [3-7]. Analysis of references and citations highlighted four additional upper-limb papers [8-11] (Total = nine papers). For comparison, 60 papers relating to the lower-limb were identified.

With respect to monitoring upper-limb use, four research areas were identified:

(1) Use of wrist-worn accelerometers to measure aspects of symmetry in upper limb activity and prosthesis wear time [3-6]

(2) Use of head-mounted video cameras to generate grasp taxonomies [7,8]

(3) Use of on-board sensing to evaluate choice of grasp [9]

(4) Use of on-board sensing to evaluate the use of a sensory feedback system and the number of grasp events [10,11]

It is worth noting that during the review process, five other studies were identified, however these were excluded from the main review because they assessed upper-limb activity without clarifying whether a prosthesis was worn at the time [12,13], or because they were only undertaken as lab-based studies [14-16]. Any future community-based applications of these methods would be of interest.

When considering all 69 papers (upper- and lower-limb), there has been a large amount of growth in publications over the past 10 years (Figure 2). Most studies recorded data for between one and two weeks (Table 1). Studies lasting for less than a week were generally those concentrating on the development of devices and algorithms, whilst studies lasting for more than one month were mostly intervention-based. Studies that compared activity monitoring to clinical scores or that compared populations typically used a 7-day protocol. Only three studies lasted for longer than three months.

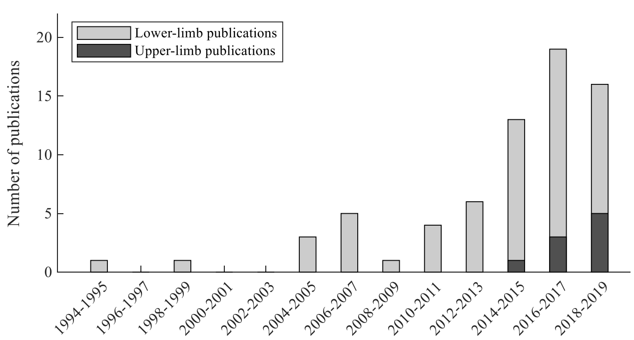

Figure 2: Number of publications per year (grouped into 2-year bins). 9 upper- and 60 lower-limb publications were published during this period.

Table 1: Recording period for studies split by the main focus of the manuscript.

Recording period	Number of studies in each cateory			
	Algorithms	***Clinical Scores***	***Interventions***	***Populations***
<7 days	6	1	1	1
7-14 days	5	13	15	6
15-30 days	1	2	5	1
31-90 days	0	2	5	1
>90 days	0	2	1	0

DISCUSSION

Although only 9 studies addressed the everyday assessment of upper-limb activity using activity monitoring methods, within the lower-limb field, these methods were observed to have increased in popularity over the past 10 years. Results suggest that upper-limb monitoring within prosthetics is approximately 10 years behind the lower-limb field, and as such we anticipate an increase in the use of real-world monitoring in the coming years.

A substantial proportion of the lower-limb studies focused on comparing prosthetic components such as different designs of foot spring. By introducing activity monitoring techniques into the upper-limb field, it will be possible to objectively compare how different types of prosthetic hand design, control methods, or socket designs impact on everyday wear and use. Other key uses of these methods in the lower-limb field included lifestyle interventions and to allow comparisons between populations. Additionally, several studies looked at comparing activity level against various clinical scores (for example K-levels). It would be interesting to use real world monitoring techniques in the upper-limb to evaluate the effects of user training methods.

The upper-limb papers identified in this review reported data on either the movements of the arm(s) (using accelerometers), or the number/types of grasps used in daily life (using video cameras or on-board processors). Neither of these measures on their own provide a complete understanding of both when the prosthesis is worn and how much it is used. For a person with an upper-limb prosthesis there are many aspects of use to consider, including: Is the arm used? Are the arm movements similar to those of an anatomical arm or do they reflect compensatory movements? Are the active capabilities of the hand, such as grasping, being used and if so, to what extent? Although the field is in its infancy, many of these issues are beginning to be explored by different groups and hence there is great potential to combine techniques. For example, by combining accelerometry for the detection of arm movements with recordings of grip choice and frequency of use, comparisons could be made with studies of upper limb activity in anatomically intact populations, between users of different types of prosthesis, or with people with different upper-limb impairments. Further by comparing measures such as ‘system on-time’ against prosthesis wear time it is possible to understand the value of advanced systems such as sensory feedback [9,10].

Prosthesis wear time is a key outcome with respect to the upper-limb, as if the user does not find the prosthesis to be of sufficient value, then it will not be worn. Consequently, reporting of prosthesis wear time is much more common in these studies than those relating to the lower-limb, where non-wear may be less of a choice with movement requiring crutches or a wheelchair when the prosthesis is not worn, thus greatly reducing functionality. Although algorithms for the automatic detection of upper limb prosthesis wear/non-wear have been developed [5,6], further validation is needed before these can be widely accepted.

This review suggests we are still some way off properly understanding real world behaviours of prosthesis users and the factors which influence them, however, many opportunities for development have also been highlighted. With growing numbers of low-cost 3D printed prosthetic hands becoming available, and the high cost of some advanced technologies, these objective methods of assessment offer the potential for significantly improving our understanding of the value, or otherwise of prostheses to users. As with all ‘real world’ monitoring technologies, ethical issues will also need to be addressed and there are several interesting discussions on these issues, which become more complex with increasing invasiveness of prosthetic technologies [17]. Such approaches would be helped by the development of agreed standards on which data should be recorded and how these should be represented, which in turn may assist with evidence-based commissioning and prescription of upper-limb prostheses.

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