A scoping review of data logger technologies used with manual wheelchairs

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ABSTRACT

In recent years, more and more studies are using data logger technologies to document driving and physiological characteristics of manual wheelchair users. However, the technologies used offer marked differences in characteristics such as measured outcomes, ease of use, burden, etc. The objective of this study is to examine the extent of research activity that relied on data logger technologies for manual wheelchair users. We undertook a scoping review of the scientific and gray literature. Five databases were searched from January 1979 to November 2014: Medline, Compendex, CINAHL, EMBASE and Google Scholar. This review retained 104 papers. The selected papers document a wide variety of systems and technologies, measuring a whole range of outcomes. Of all technologies combined, 16.8% were accelerometers installed on the user, 14.8% were magnetic odometers or odometers installed on the wheelchair, 10.2% were accelerometers installed on the wheelchair and 8.67% were heart monitors. So, it is not surprising that the most reported outcomes were distance, speed and acceleration of the wheelchair, and heart rate. In the future, it may be necessary to reach a consensus on what outcomes are important to measure and how. Technological improvements and access to less expensive devices will probably make it possible to easily measure many important outcomes at relatively low cost.

BACKGROUND

As a way to facilitate independent mobility and promote social participation of individuals with mobility disabilities, wheelchairs are frequently prescribed, making them a significant intervention in the world of rehabilitation. Manual and powered wheelchairs are prescribed to nearly 265,000 Canadians (Shields, 2004) and 3.3 millions Americans (Laplante and Kaye, 2010) who experience difficulty walking. It is not surprising that it represents an important factor of community reintegration (National Council on Disability, 1993; Noreau *et al.*, 2000; Scherer *et al.*, 2001). However, relatively little is known about the direct impact wheelchairs have on a user's daily activities and participation. To understand the use and impact of wheelchairs, it is important, from a clinical point of view and for researchers to document the mobility characteristics of wheelchair users and to obtain an accurate account of their activity levels. In recent years, studies have increasingly focused on recording driving and physiological characteristics of manual wheelchairs users using objective methods that employ electronic monitoring technologies (i.e. "Data loggers").

Of the data logging work that has been performed, the technologies used offer marked differences in characteristics such as measured outcomes, ease of use, burden, etc. This disparity in the literature may be confusing to therapists and researchers alike, as well as make it difficult for others to implement for their own studies. Thus, in order to obtain an overview of what has been done until now to quantify and objectively assess manual wheelchair use, the goal of this study is to identify and describe most common data loggers, their related outcomes, and the underlying technology features used to measure manual wheelchair use and activity, as well as physiological characteristics of wheelchair users.

METHODS

We undertook a scoping review of the scientific and gray literature to examine the extent of research activity relied to data logger technologies for manual wheelchair users. Because the literature corresponding to this goal is broad, as well as the technologies implicated, it was more appropriate to conduct a scoping review rather than a systematic one (Arksey and O'Malley, 2005). Moreover, our goal was not to answer a specific research question, but rather to map the available literature about a specific research area (Levac *et al.*, 2010).

Literature search

A flowchart describing our search and review method was established. First, a research assistant (occupational therapist with a MSc level) searched four databases: Medline, Compendex, CINAHL and EMBASE, using specific keywords linked by Boolean operators. We limited our search to publication dates between January 1979 and November 2014. Subsequently, we searched in

Google Scholar, using a combination of keywords similar to the one used for the databases. Since literature on the topic of interest may come from different sources, we did not look only for articles published in peer-reviewed journals but also for grey literature (via Google Scholar), including theses and conferences proceedings.

Study selection

In terms of technologies, the publication was eliminated if it was a research review, if it was not related in any way with wheelchairs or wheelchair users, if it has no abstract and/or text available, and if it was not in English or French. Furthermore, we excluded those devices that were not fully described, were not suitable for use in the community, were only used for comparison, were not intended to continuously collect data, and/or were not intended to collect data (not "loggers"). The outcomes of interest were measures of mobility (e.g. speed, distance, etc.) and physiology (e.g. heart rate, VO_2, energy expenditure, etc.).

To start the selection process, all citations from databases were exported to EndNote, where we applied the "Find Duplicates" option. A manual check-up of the citations was also made to find other duplicates which would have not been noticed by the system. A search was then performed in Google Scholar as a method to find other relevant papers. Duplicates were noted and discarded. The research assistant reviewed all the titles and/or abstracts of the publications that were identified and discarded irrelevant ones. After this screening, articles remaining were read to further assess their eligibility, thus completing the selection process.

Data extraction

After publications relevant for this scoping review were identified, the research assistant, with the help of one co-researcher (FR), identified/described for each study: 1) if it was a developmental or an experimental study; 2) a brief description of the system; 3) the way the device was powered and its battery life; 4) the measured outcomes; 5) the sensing equipment (e.g. accelerometer, gyroscope, compass, GPS); and 6) if the system was fixed on the wheelchair or on the wheelchair user. All data were recorded in a table developed specifically for the purpose of this study.

Data analysis

We used descriptive quantitative analysis to investigate data extracted from the individual studies identified. Specifically, we calculated the frequency of utilization of each technology/equipment implicated and the frequency of each outcome measured. Where possible, outcomes were grouped into relevant categories (e.g. outcomes related to speed or velocity were grouped).

RESULTS

The search strategy in databases and Google Scholar located 6,087 papers (once duplicates were eliminated). After the screening of titles and/or abstracts, 208 papers remained according to our initial exclusion/inclusion criteria. Of those articles, a total of 104 papers, specifically related to manual wheelchairs, were kept for analysis. Although we wanted to examine the extent of research activity that focused on data logger technologies for manual wheelchairs, some studies (n=21) presented a system that was used both with manual and power wheelchairs. Note that a paper may have described more than one logger, one logger was often used in more than one paper, and one logger often includes more than one technology.

Table 1 presents the frequencies related to the technologies reported. Regarding all the technologies reported (n=196) in the selected papers, 54.6% (n=107) were installed on the wheelchair and 45.4% (n=89) were installed on the user. All technologies combined, 16.8% (n=33) were accelerometers installed on the user, 14.8% (n=29) were odometers installed on the wheelchair, 10.2% (n=20) were accelerometers installed on the wheelchair and 8.67% (n=17) were heart monitors. So, it is not surprising that the most reported outcomes were distance (n=42; 11.5%), speed (n=36; 9.9%), heart rate (n=35; 9.6%) and acceleration (n=22; 6.0%). Table 2 presents the frequencies related to groups of measured outcomes.

Three systems were presented or used in a significant number of papers: 1) a custom data logger (magnetic odometer) developed by researchers at University of Pittsburg (Human Engineering Research Laboratories (HERL)), mentioned in 19 papers (e.g. Tolerico *et al.*, 2007); 2) heart rate monitor developed in Finland, mentioned in 10 papers (e.g. Sindall *et al.*, 2013); and 3) an accelerometry-based activity monitor developed in Netherlands, mentioned in 7 papers (e.g. Postma *et al.*, 2005).

For only 25 of the 80 devices reported (31.3%), information regarding the way the device was powered was reported in the paper. Similarly, accurate information concerning battery life of the systems was given for only 24 devices (30.0%). However, for some systems (n=13; 16.3%), when battery life was not clearly specified, details concerning the duration they were "on" for the experiment were presented. We have assumed in those cases that they were not recharged during that period.

Table 1. Technologies reported in the selected papers

Technologies	# of times reported	% of total technologies
<u>On the wheelchair</u>		
1. Odometer	29	14.8%
2. Accelerometer	20	10.2%
3. Gyroscope	11	5.6%
4. Pressure sensors/Switch	11	5.6%
5. Force sensing technology	6	3.1%
6. GPS (outdoor)	5	2.6%
7. Load cells/FT	4	2.0%
8. Wireless positioning system (indoor)	4	2.0%
9. T° sensors	4	2.0%
10. Electrocardiogram	3	1.6%
11. Potentiometer	2	1.0%
12. Humidity sensors	1	0.5%
Other sensors	7	3.6%
Total: Technologies on the wheelchair	**107**	**54.6%**
<u>On the user</u>		
1. Accelerometer	33	16.8%
2. Heart monitor	17	8.7%
3. Thermistors	9	4.6%
4. Metabolic cart	8	4.1%
5. Galvanic skin response sensor	6	3.1%
6. Near body T° sensor	6	3.1%
7. Electrocardiogram	3	1.5%
8. Gyroscope	2	1.0%
9. Force sensing technology	2	1.0%
10. Respiration monitors	1	0.5%
11. Oximeter	1	0.5%
12. Compass	1	0.5%
Total: Technologies on the user	**89**	**45.4%**
Total: All technologies	**196**	

Table 2. Outcomes measured by the systems reported in the selected papers

Outcomes	# of times measured	% of total outcomes
Kinematic (e.g. distance, speed, acceleration, angular velocity of the wheelchair)	129	35.4%
Kinetic (e.g. propulsion force, torque)	10	2.7%
Movement/Activity (e.g. driving time, duration of physical activity, bouts, strokes, activity counts)	71	19.5%
Body posture	6	1.7%
Sitting (e.g. pressure-relief activities, seat pressure, sitting time)	27	7.4%
Physiological (e.g. heart rate, respiration, body temperature, ECG, energy expenditure)	111	30.5%
Others (e.g. vibration)	10	2.8%
Total	**364**	

DISCUSSION

The selected papers presented a wide variety of systems and technologies, and measured a wide range of outcomes. This may be attributed, to some extent, to the fact that 50 devices were reported only once. Moreover, some papers used the same data logger hardware, but did not necessarily measure the same outcomes. Technologies such as accelerometers, odometers and heart monitors, and outcomes related to kinematics (distance, speed, acceleration) and heart rate were most common. In the future, it will be necessary to reach a consensus on what outcomes are important to measure and how, as suggested in part by Hoenig *et al.* (2007).

Some systems, although having the potential to be used in the community, are currently only reported as used in the laboratory. For instance, for this review, we did not include SMART^{Wheel} or similar systems, based on these reasons: 1) no one has reported (to our knowledge) data recorded by these devices in the community; and 2) they are unlikely to be used in the community context for practical reasons (they are expensive, delicate and cannot store much data before exhausting their memory).

A flexible system, like the one developed by HERL, that can measure a variety of outcomes and can integrate different commercial sensors, is potentially very promising for a variety of uses. Technological developments and reducing costs may make it possible to easily measure, in the future, many significant outcomes at low cost.

CONCLUSION

Over the past two decades, data loggers have increasingly been used to provide innovative and quantitative documentation of wheelchair users' activities through a variety of outcome measures. As the relevant technologies continue to improve, we fell it may be time to discuss which outcomes are most important, as well as the best way to document them using data loggers.

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