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Ambulatory monitoring of physical activity in working situations, a validation study

M. Uiterwaal†§*, E. B.C. Glerum‡, H. J. Busser§ and R. C. van Lummel§

†Department of Human Kinetic Technology, Haagse Hogeschool, Johanna Westerdijkplein 75, 2521 EN, The Hague, The Netherlands
‡IVAS; Heliomare, Relweg 51 1949 EC, Wijk aan Zee, The Netherlands
§McRoberts BV, Raamweg 43, 2596 HN, The Hague, The Netherlands

How to assess a patient's functional physical motility in non-laboratory situations has been a problem for the medical services for a tong time. A measurement system using accelerometry (DynaPort ® ADL Monitor) has been developed to cope with this problem. ft is a lightweight recorder that is worn around the waist ft uses accelerometry to ambulatory monitor the Activities of Daily Living (ADL). In this study the reliability of the monitor in two working situations of one patient has been assessed: maintenance mechanic and messenger in a city hall All actions were simultaneously videotaped. The video recording was interpreted by an observer. Independent of this, the acceleration signals were translated by the monitor software into one of the basic postures or movements: locomotion, standing, sitting, lying and playing. Every second the monitor and observer interpretation were compared and maximal and minimal validity percentages were calculated for all classes and for the total measurement The overall (minimal) validity was found to be higher than 86%. The maximal validity was 93% of the total measurement in the patient's job as a maintenance mechanic. Considering the simple instrumentation of the ADL monitor this validity is considered good.

Introduction

One of the difficulties in clinical assessment is how to obtain accurate data in a non-laboratory environment. Ambulatory activity monitors are used to objectively measure the quantity of body activity or heart rate over a prolonged period of time outside the laboratory. Often single accelerometers on, for example, the wrist [1-3] or waist [4], or heart rate monitors [5, 6] are used. These provide a measure of a single aspect of overall physical activity. With wrist activity monitors it has been shown that naturalistic assessment of drug-induced effects on the motor activity of hyperactive children is feasible [7, 8].

Using the ADL Monitor, more insight in the Activities of Daily Living (ADL) can be obtained, especially outside the laboratory or clinic. ADL assessment can help to examine physical work demand at the workplace. Other applications of the monitor include evaluation of response to medication, effect of treatment and objective diagnosis support.

The DynaPort ADL Monitor [9] was developed to support clinical decision making. It measures the *Activities of Daily Living,* by translating recorded accelerations (including gravitation) into basic postures and activities: lying, sitting, standing and locomotion. Subclasses like sitting straight or backwards, lying face up, face down or on a side as well as step frequency of walking can be distinguished. Besides, intensity and frequency of movement are calculated.

So far, activity monitoring using accelerometry was used and validated on adults [10] and children [11]. The aim of this study was to examine the reliability of the ADL classification by the monitoring system on adults in two occupational situations at the workplace.

Methods

Patient

The patient under study (male, 42 years old) is a maintenance mechanic suffering from low back pain. The clinical diagnosis was dysfunction in L4-L5 based on a degenerative process. He is able to work for 4 h per day in his present job. The aim of his employer is to get the patient back to work on a fulltime job. In order to be able to advise which of two jobs (maintenance mechanic, messenger city hall) is the least strenuous for the patient, objective data of reductions and provocations of low back pain must be obtained. The provocations and reductions were assessed beforehand by medical executives.

The result of the comparison between the two jobs have been submitted for publication [12].

Measuring device

Using accelerometry the monitor logs the activities of daily living (postures and movement). Its hardware consists of a compact wireless digital recorder, 125 x 95 x 34 mm, 295 g (excluding three penlight batteries and PC-card (PCMCIA)). It records the signals of three unidimensional DC-coupled acceleration (piezo-resistive) sensors. Two sensors are placed inside the box perpendicular to each other and one sensor is placed externally. The sensors have a range of 14 g and a resolution of 0.02 g. In this study a 10 Mbyte memory card is used, allowing continuous measurement for 24 h. The recorded signals are imported in a computer and processed (see *Analysis).*

Two sensors are placed in the recorder that is worn in a belt around the waist (figure 1). Optionally one extra

**Author for correspondence at §.*

sensor can be applied on the left upper leg for additional specificity of ADL assessment. A patent is pending on this type of activity assessment.

Procedure

The patient was measured twice with the monitor. The first measurement was made during his regular work as a maintenance mechanic. The second day he worked as a messenger in the local city hall. The measurements lasted for 3.5 and 3.2 h, respectively. In the study the patient was free to work as usual.

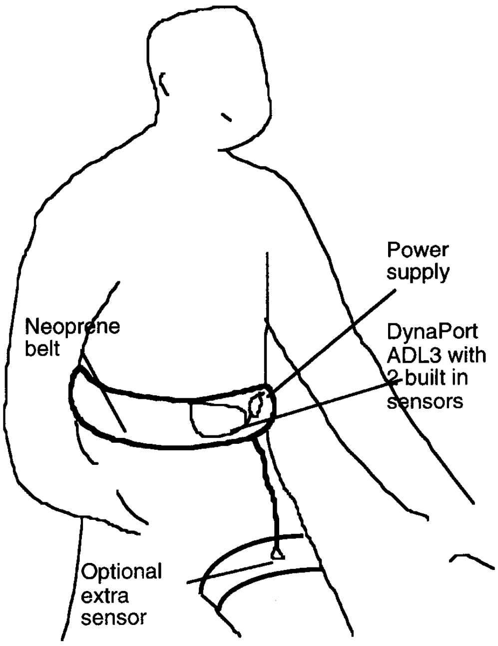

Figure 1. The system is worn beneath the clothes. The external sensor is placed in an elastic strap and worn on the left upper leg.

Both measurements were fully videotaped, except for the coffee-break. Special care was taken to record the start of the monitor on video, because of the need of synchronization between the videotapes and the recorded signals to allow accurate comparison between the different data collections.

Analysis

The registered acceleration signals are 'translated' into one of the main classes of postures and movements by the ADL Monitor software. By implementing the techniques for dynamic analysis using body fixed sensors [13] as obtained through the EUREKA project DYNAPORT the translation is fully computerized. The software runs on an IBM-compatible personal computer. See figure 2.

All activities were divided in one of the main five categories: lying, sitting, standing, locomotion and swing/seesaw. (The last category was introduced to meet the special demands of children's monitoring).

The video pictures were interpreted by an observer. Every moment a change of class was observed this change was entered into a computer by means of a computer interface (figure 3), the raw signals are not visible, so the observer will not be tempted to classify the video according to the signals. The registered acceleration signals were translated into one of the main classes by the software. This way strings of classification data for both the video and monitor data were produced. The obtained video and monitor classifications were compared per second by the software.

For the comparison of the video and monitor data the following values and notations were defined:

T(s): Total measurement **t**ime.
T_{vc}(5): Total time that class 'c' occurred according to **v**ideo.
T**m**$_c$(s): Total time that class 'c' occurred according to **m**onitor.

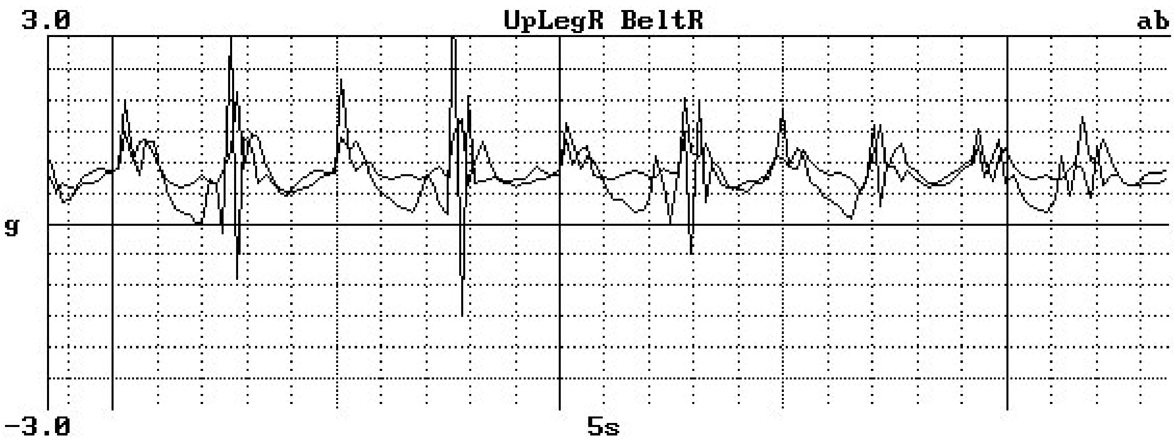

Figure 2. A typical acceleration signal for walking obtained by the monitor.

A$_c$ (s): Total time that video and monitor **a**gree about class ‘c’ at the same second.

M$_c$(s): **M**aximal time that video and monitor agree about class ‘c’.

For the ***evaluation*** of the video and monitor data comparison the following values and notations were defined:

Measurement validity:

$$V_{\min} = \frac{\sum_c A_c(s)}{T(s)} \qquad (1)$$

$$V_{\max} = \frac{\sum_c M_c(s)}{T(s)} \qquad (2)$$

Class sensitivity; based on video times:

$$S_{\min} = \frac{A_c(s)}{Tv_c(s)} \qquad (3)$$

$$S_{\max} = \frac{M_c(s)}{T\upsilon_c(s)} \qquad (4)$$

Class predictive value; based on monitor times:

$$P_{\min} = \frac{A_c(s)}{Tm_c(s)} \qquad (5)$$

$$P_{\max} = \frac{M_c(s)}{Tm_c(s)} \qquad (6)$$

The minimal validity (V_{min}) is the total time the video and the monitor agree in the total measurement about all classes at the same second expressed as the percentage of the total measurement time. The maximal validity (V_{max}) is the total time the video and the monitor agree in the total measurement about all classes (i.e. not necessarily at the same second) expressed as a percentage of the total measurement time.

Especially in measurements with many swift transitions of activity, the minimal validity is low while the total duration of the classes scored by the monitor may actually agree with those of the video. Therefore a maximum validity is defined in which the reaction-time error is compensated.

The actual validity will lie somewhere between V_{min} and V_{max} Minimal and maximal monitor validity can be calculated per class and per measurement. The validity per class is split in two: the sensitivity being the percentage of the actual activity that is adequately recognized by the monitor, and the predictive value being the percentage of the monitor report that is correct.

If for example the sensitivity for lying is 100%, this means that 100% of the actual lying was detected. But if the monitor is too sensitive for lying, i.e. more lying is

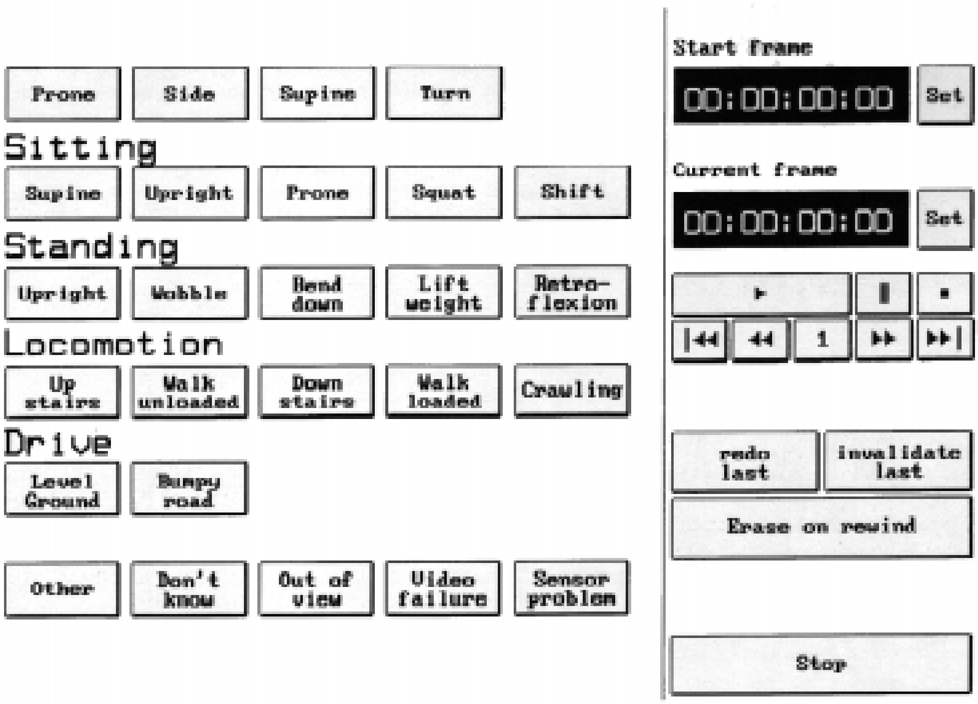

Figure 3. The computer interface for evaluating the video pictures.

detected by the monitor than actually happened, part of what the monitor reports as lying will be false. The predictive value is the percentage of what the report calls lying that actually was lying. But even if this is 100%, this does not mean that all the lying was detected. Therefore both sensitivity and predictive value have to be considered.

Results

Figure 4 gives an overview of the total time the various classes were observed on video for both the maintenance mechanic as the messenger.

The total time for lying in this study (1.22 min) is too low to evaluate the monitor's performance for this class. As can be seen in the figure 4 (a) and 4 (b), lying did not comprise a long time. In the job of the maintenance mechanic it did not take place at all. Therefore in figure 5 (a), no sensitivity (S_{min}, S_{max}) and predictive value (P_{min}, P_{max}) could be obtained for this category. In a previous study [9] where lying took place longer the sensitivity for lying was 91% and the predictive value was 96%.

In the job as a messenger the sensitivity for standing was low, but the standing that was detected was detected correctly (predictive value is very high).

The overall (minimal) agreement, that is video and monitor compared per second, was found to be 86.16%

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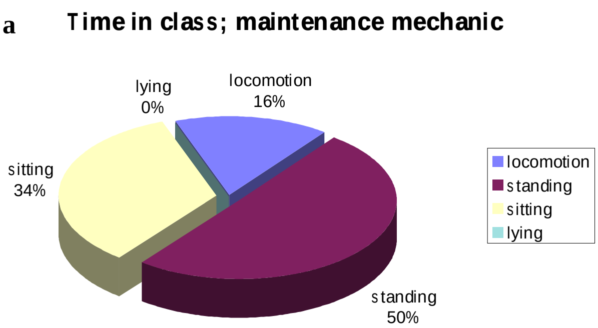

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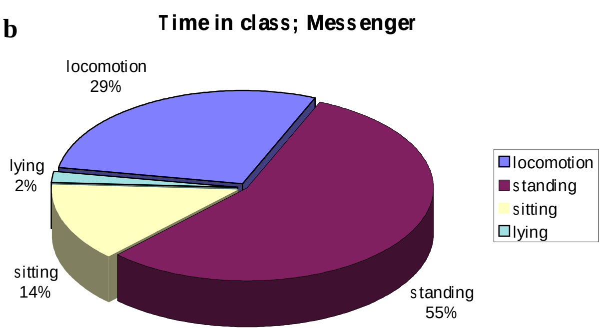

Figure 4. (a) Total time that a class occurred in the measurement as a maintenance mechanic. (b) Total time that a class occurred in the measurement as a messenger.

and 88.3% for the messenger and the maintenance mechanic, respectively (figure 6). The maximal agreement for the whole measurement, was 89.32% to 93.08%, respectively.

Discussion

The patient reported that he was not hindered by the monitor during his work, so a clear review of the

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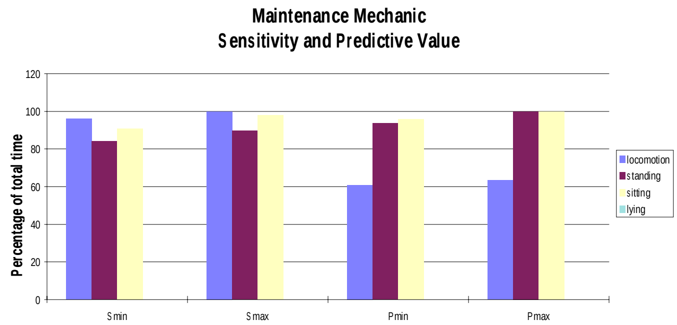

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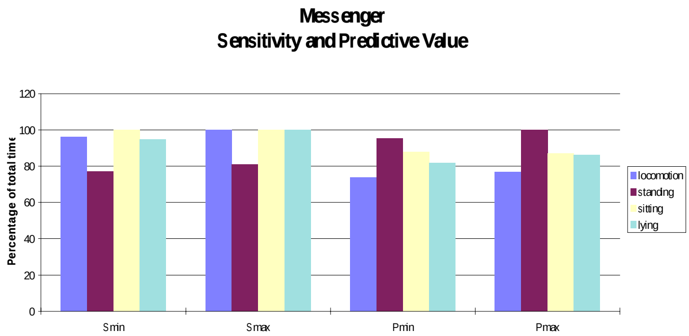

Figure 5. (a) Sensitivity and the predictive value per class of the monitor for the job of maintenance mechanic. (b) Sensitivity and the predictive value per class of the monitor for the job of messenger.

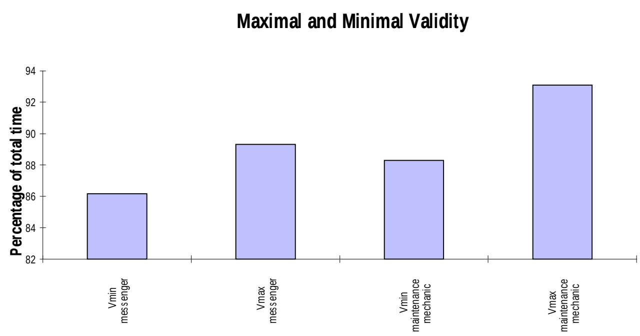

Figure 6. Minimal and maximal overall validity of the monitor in the two jobs.

postures and motions during work conditions was obtained.

The sensitivity in the maintenance mechanic job was very high, indicating that most postures were detected. The predictive value for locomotion was not very high, indicating that according to the monitor locomotion took place a longer time than according to the video-observer. The other postures have a high predictive value and a high sensitivity.

A source of lack of agreement is the impossibility to translate some activities that take place into one of the main classes of the monitor. There are situations when the observer cannot classify the type of activity. The observer will enter the situation as 'Don't Know' in the computer interface (figure 3). The monitor will have to follow the algorithms in the software and specify a class. This difference between the observer and the monitor will result in a error which cannot be avoided without adding more sensors.

Slight differences between the monitor and the video scores exist due to observer reaction time variations, monitor detection delay and rounding of the moments of transitions to whole seconds. when comparing the video and monitor data at the same moment (A_c) these differences cumulate into an error causing an underestimation of the actual validity. Therefore also the maximal time the monitor and video agree, although not at the same second, about a class is calculated (M_c). This will result in an overestimation of the actual time of agreement. The actual total time of agreement will lie somewhere between A_c and M_c.

The observation that the monitor detects more locomotion than standing might be due to wobbling of the patient. The wobbling is translated as locomotion by the monitor and seen as standing by the video-observer.

An advantage of measuring with the ADL Monitor is that the measuring device is not visible for other people. when videotaping someone, the person feels observed and might adjust his behaviour. This might effect the conclusion of the comparison of the two jobs, but is less relevant for this study, as only the reliability of the detection is validated. During this study, people reacted to the video camera, but did not observe the monitor.

The agreement is considered good. A more detailed and more specific assessment of postures and movement would involve more instrumentation, which can make the concept of ambulatory monitoring and assessment of work demand at the workplace very difficult, if not impossible.

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