

Est.
1841

YORK
ST JOHN
UNIVERSITY

Anderson, Jayne L., Green, Angela J., Yoward, L S and Hall, Howard (2017) "Validity and reliability of accelerometry in identification of lying, sitting, standing or purposeful activity in adult hospital inpatients recovering from acute or critical illness: a systematic review". *Clinical Rehabilitation*, 32 (2). pp. 233-242.

Downloaded from: <https://ray.yorks.ac.uk/id/eprint/2347/>

The version presented here may differ from the published version or version of record. If you intend to cite from the work you are advised to consult the publisher's version:

<http://journals.sagepub.com/doi/full/10.1177/0269215517724850>

Research at York St John (RaY) is an institutional repository. It supports the principles of open access by making the research outputs of the University available in digital form. Copyright of the items stored in RaY reside with the authors and/or other copyright owners. Users may access full text items free of charge, and may download a copy for private study or non-commercial research. For further reuse terms, see licence terms governing individual outputs. [Institutional Repositories Policy Statement](#)

RaY

Research at the University of York St John

For more information please contact RaY at
ray@yorks.ac.uk

Validity and reliability of accelerometry in identification of lying, sitting, standing or purposeful activity in adult hospital inpatients recovering from acute or critical illness: a systematic review

Jayne L Anderson^{1,2}, Angela J Green¹, L. Samantha Yoward² and Howard K Hall³

¹ Physiotherapy Department, Hull and East Yorkshire Hospitals NHS Trust, UK

² School of Health Sciences, York St John University, UK

³ School of Sport, York St John University, UK

Mrs Jayne Anderson, Lecturer Practitioner Physiotherapist, Therapies Centre, Hull Royal Infirmary, Anlaby Road, Hull, East Yorkshire, United Kingdom. HU3 2JZ. Telephone: 01482 605293. Fax: 01482 674721. Email: jayne.anderson@hey.nhs.uk.

Dr Angela Green, Lead Clinical Research Therapist, Therapies Centre, Hull Royal Infirmary, Anlaby Road, Hull, East Yorkshire, United Kingdom, HU3 2JZ. Telephone: 01482 605291 Fax: 01482 674721. Email: angela.green@hey.nhs.uk

Dr Samantha Yoward, Senior Lecturer, School of Health Sciences, York St John University, Lord Mayor's Walk, York., United Kingdom, YO31 7EX. Telephone: 01904 876331. Fax: 01904 876500. Email: l.yoward@yorks.ac.uk

Professor Howard Hall, University Head of Research, 208, De Grey Building, York St John University, Lord Mayor's Walk, York, YO31 7EX. Telephone: 01904 876302. Fax: 01904 876500. Email: h.hall@yorks.ac.uk

Corresponding author Jayne Anderson

Abstract

Objective: To investigate the validity and reliability of accelerometers to detect lying, sitting and standing postures or purposeful activity in hospitalised adults recovering from acute or critical illness.

Data sources: CINAHL, MEDLINE, EMBASE, AMED, Cochrane Library, PEDro, PsycINFO and SPORTDiscuss were searched from inception to June 2017. Professional networks and reference lists of relevant articles were also searched. The main selection criteria were hospitalised adults with acute or critical illness and studies investigating the validity or reliability of accelerometers to identify body position or purposeful activity.

Review methods: Two authors individually assessed study eligibility and independently undertook methodological quality assessment and data extraction from selected articles. A narrative synthesis of the data was undertaken.

Results: Fifteen studies, collectively enrolling 385 hospitalised participants were identified. Populations included stroke, the elderly, acute exacerbation of chronic respiratory disease, abdominal surgery and those recovering from critical illness. Correlations of $r = 0.36$ to 0.98 and levels of agreement of $\kappa = 0.28$ to 0.98 were reported for identification of lying, sitting or standing postures. Correlations of $r = -0.39$ to 0.98 with general activity were found, with $r = 0.94$ and 0.96 reported for step count. The reliability of accelerometry measurement was investigated in one study evaluating step count quantification (ICC 0.99 , 95% CI $0.99-1.00$).

Conclusion: The validity of accelerometers to determine lying, sitting and standing postures or quantify purposeful activity within hospitalised acute or critically ill populations is variable. The reliability of accelerometry measurement within this setting remains largely unexplored.

Introduction

A recent study concluded that high levels of inactivity in hospitalised adults are not exclusive to the elderly.(1) Critical illness survivors spend up to 90% of the day in sedentary postures (lying or sitting) in their final days of hospital stay.(2) Immobility whilst in hospital contributes to irreversible functional decline in older populations.(3, 4) Conventional methods of monitoring activity undertaken by hospitalised adults such as direct observation or self-report are subject to operational weaknesses.(5-7) Wearable motion-sensing technologies (accelerometers) could offer an objective and unobtrusive alternative. Furthermore, some possess an ability to identify body position (lying, sitting or standing); enabling the clinician to identify those who are adopting prolonged periods of sedentary behaviour in lying or sitting positions. In order for accelerometers to be considered a viable alternative, there is a need to understand the extent of investigation of validity and reliability that has been undertaken within the hospital setting.

This study aims to systematically review evidence investigating the validity or reliability of identification of lying, sitting or standing postures or purposeful activity using accelerometers in hospitalised adults recovering from acute or critical illness. These populations are likely to undertake activities which are of low intensity and performed at a slow speed. Purposeful activity is operationalised as changing or maintaining body position, moving (activity) and walking, corresponding with definitions provided by the World Health Organization International Classification of Functioning, Disability and Health (ICF).(8)

Methods

The methods, results and discussion sections are reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

checklist.(9) A protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO CRD 42013006707).

Eligibility criteria

Article type or language was not limited. English translations of abstracts were obtained for any non-English articles identified. Table 1 lists the eligibility criteria for inclusion.

Table 1 **Eligibility criteria table to lie here**

Studies were excluded if accelerometers were being investigated in combination with other technology (e.g. gyroscopes). Those investigating the validity of accelerometry specifically for measurement of energy expenditure, sleep, finger tapping, falls, tremor, balance or aspects of gait analysis (e.g. trunk asymmetry) were also not eligible.

Information sources and search strategy

The databases CINAHL, MEDLINE, EMBASE, AMED, Cochrane Library, PEDro, PsycINFO and SPORTDiscuss were searched from inception to June 2017. The literature search performed within MEDLINE is detailed in Appendix 1 as an example. Reference lists of included articles and systematic reviews deemed relevant were searched to identify any further potential evidence sources.

Study selection and data collection

Two reviewers (JA and AG) assessed article eligibility independently. A review of title and abstract (stage one) was followed by a full text review of papers identified from the first stage as potentially satisfying eligibility criteria. Any opposing conclusions between both reviewers regarding study eligibility were resolved through discussion, without the need for a third reviewer. Both reviewers were uncertain of the eligibility of four studies. The authors of these studies were contacted to assist in determination of their eligibility.

A data collection form was developed, piloted and used for data extraction from studies selected for inclusion following full text review. This process utilised the Population, Intervention, Comparator, Outcome and Study Design (PICOS) framework.⁽⁹⁾ Data extracted by both reviewers was compared, discussed and agreed as an accurate representation for each study.

Both reviewers worked independently during the review of title and abstract, full text review, assessment of methodological quality and data extraction. Methodological quality of included studies was determined using the Critical Appraisal Skills Programme (CASP) cohort study checklist (version 31st May 2013). A copy of this checklist is found in Appendix 2. Nine of the 12 questions required a 'yes', 'no' or 'can't tell' response. Clearly reported information was marked as 'yes' and scored 1. 'No' or 'can't tell' answers both scored 0. Using this method it was possible to calculate a score related to the specific aspects of methodological quality considered within these particular questions. Two of the nine questions possessed an 'a' and 'b' section, meaning a maximum score of 11 could be achieved. The final three questions within the CASP checklist were not designed to receive a score. These focused on the quality of the study results, their precision and implications for practice. Consideration was given to these particular questions during the process of data extraction and synthesis.

Data synthesis

Data concerning study results, their precision and implications for practice was assimilated using information from the data extraction forms and CASP checklists. Numbers lost to follow up with reasons were extracted to assist in understanding why patients might withdraw from studies of this type. Percentage agreement between both reviewers for methodological quality assessment was calculated based on items within the CASP checklist that could be scored. In order to correct for chance agreement and take all three possible responses ('yes', 'no' or 'can't tell') into consideration a kappa (κ) co-efficient was also calculated using IBM SPSS (Version 20.0).

Preliminary synthesis compiled patient populations, sample sizes, study objectives and findings. Data on the accelerometer models was synthesized, including the epoch lengths, where accelerometer data was accumulated over a specific time period (e.g. one second). A systematic assessment of the evidence was developed through narrative synthesis.

Results

Study selection

The literature search identified 3954 articles. Following duplicate removal, 2743 articles progressed to the first stage review of their title and abstract. Figure 1 details the evidence selection process. No non-English articles ($n = 51$) were deemed eligible following a review of their English abstracts. Fifty-one articles satisfied the inclusion criteria, progressing onward to a full text review. Three further articles were identified following hand searching of reference lists. The authors of four studies were contacted to enable decisions to be made regarding article eligibility. Fifteen studies were included following full text review,

which initially enrolled 385 hospitalised participants in total. Sample sizes ranged from five (10, 11) to 110.(12)

Figure 1: Flow diagram detailing the evidence selection process to be placed here

Methodological Quality

Methodological quality scores ranged from three to ten out of 11, based on the items able to be scored. The mean (SD) quality score was 6.2 (2.3) points. Reviewers achieved 87% agreement on the 11 quality assessment items able to be scored ‘1’ or ‘0’. Inter-observer agreement was $\kappa = 0.60$ ($p < 0.001$), indicating moderate agreement.(13) Kappa analyses took all three possible responses (‘yes’, ‘no’ or can’t tell’) into consideration. Where one author entered ‘no’, the other often recorded ‘can’t tell’, although both responses scored ‘0’.

Accelerometers investigated, application and populations

Most accelerometers were commercially available. Table 2 details the accelerometer models investigated, their application, the populations investigated and main findings. Most were multiaxial, quantifying movement in more than one dimension. One commercial model, the activPAL, was uniaxial.(14,15) Nine studies investigated identification of body position or postural transition.(11,14-21). Three investigated quantification of step count,(14,22,23) whilst four investigated quantification of general activity. (10,12,24,25)

Table 2: Accelerometer models investigated

Investigation of validity or reliability

All studies investigated validity, comparing accelerometer data against observation, (10-12,15,19-24) video recordings,(14,17) other accelerometer models(16, 18) or self-report.(24) One study also investigated accelerometer reliability, evaluating quantification of step count using the AMP 331 accelerometer over repeated known distances in critical illness survivors. An ICC (95% CI) of 0.99 (0.99-1.00) was reported.(22)

Identification of body position or postural transition

Accelerometers placed in isolation on the thigh or wrist did not differentiate between lying and sitting positions.(14,16,18) A thigh mounted uniaxial activPAL found no misclassification of time spent in sedentary (lying/sitting) or upright positions within elderly or stroke inpatients compared to video recordings.(14) The activPAL was also used as the criterion measure in two studies.(16,18) As this model cannot differentiate between lying and sitting itself,(26) it could not be determined whether the thigh mounted custom made model(16) or wrist worn GENEActiv(18) undergoing investigation of their validity could distinguish between these two postures themselves.

Accelerometers placed in combination permitted differentiation between lying and sitting.(11,14,17,19-21) Two studies investigated AugmenTech wireless models positioned on the thigh and ankle of the same limb, using observation as a comparator.(20,21) One study reported a mean (range) percentage agreement for recognition of lying and sitting of 98.3% (90.81-100%) and 96.9% (95.28-98.61%) respectively.(20) The other study reported correlations of time spent in lying and sitting positions of $r \geq 0.97$ ($p < 0.001$). (21) Thigh and sternum combinations of the activPAL permitted differentiation of lying to sitting and sitting to standing postural transitions.(14) Whilst the PAL2, positioned above and below the knee

correctly identified lying to sitting postural transitions, it over or underestimated sit to stand and stand to sit transfers ($\leq 10.5\%$).⁽¹⁷⁾

Identification of activity intensity

Three studies investigated wrist worn Motion Logger models.^(12,24,25) Another study investigated a custom made design.⁽¹⁰⁾ One study investigating a Motion Logger model evaluated the ability of three different measurement modes to quantify activity intensity (Zero Crossing Mode (ZCM), Time Above Threshold mode (TATM) and Proportional Integrated Mode (PIM)).⁽¹²⁾ The findings suggested no mode was superior to another in capturing activity intensity in older adults with dementia, with only moderate correlations when compared against direct observation (see Table 2).

ZCM and TATM modes determined a mean (SD) agreement of 80% (12%) when compared against self-reported activity intensity in patients following post-operative major abdominal surgery. Individual participant correlations ranged from 0.4 to 0.8 ($p < 0.001$).⁽²⁴⁾ PIM, ZCM or TATM modes were also used to identify frequency and duration of activity in critically ill patients resident in the ICU.⁽²⁵⁾ Mean (range) agreement between observed frequency of activity and that registered by the accelerometers was 76% (40-100%) and 66% (40-80%) for duration of activity.⁽²⁵⁾

A further study investigated a custom made accelerometer, comparing identification of activity using a single placement site (hip) to a combination of three different body sites (hip, wrist and ankle).⁽¹⁰⁾ Placement in combination produced the best correlations between observed active time and that registered by accelerometry in older inpatients (ICC 0.93 ($p \leq 0.001$)). Accelerometers placed in combination were also superior in estimation of time spent in activity, although still exhibiting a tendency for underestimation (see Table 2). The worst results for single or a combination of placement sites were encountered during antalgic gait

therapy, suggesting the ability of accelerometers to identify activity may depend on the type of activity undertaken (Table 2).

Quantification of step count

Excellent results have been reported for quantification of step count in ankle mounted commercial Actigraph GT3X+, StepWatch 3.0 and AMP 331 accelerometers.(22,23) The best results for the Actigraph GT3X+ were found when using the Low Frequency Extension Filter (LFE), with results comparable to the StepWatch 3.0 when investigated within older inpatients, using observation as a comparator (see Table 2).(23)

The activPAL was not valid within hospitalised older and stroke populations, especially at walking speeds of $\leq 0.47\text{m/s}$.(14) Less error was encountered when positioned on an unaffected limb in hospitalised stroke and home dwelling patients post hip fracture, with absolute percentage errors (APE) of 26.91% reported compared with 53.40% when worn on an affected limb.(14) This finding suggests placement on a non-affected lower limb may improve step count quantification in populations including stroke and post hip fracture in thigh mounted devices.

Patient retention in studies

Studies encountered withdrawal of 4% to 25% of participants due to technical problems with the accelerometers or criterion measures, premature termination of monitoring or participants' inability to complete movement protocols where included.(17,19,21) Discharge from hospital prior to data collection accounted for the withdrawal of 15% of participants in one study.(19) Unscheduled patient transfers accounted for loss of data in 5% of participants initially resident in an ICU.(25) Two participants (4%) in one study withdrew consent following enrollment and a period of data collection due to a dislike of being

observed continuously.(21) This finding highlights the importance of considering the most appropriate criterion measure for validation studies of this type, to ensure patient retention and prevent loss of data.

Further loss of data from one of 20 participants (5%) occurred due to a refusal to repeat aspects of walking protocols.(22) A dislike of wearing the accelerometers, necessity for medical procedures or deterioration in condition precipitated withdrawal of 4% to 15% of participants in some studies.(16,19,21) Of 38 participants who agreed to wear an accelerometer to determine step count during a hallway walk, only 21 (55%) consented to wear the devices for a full day to quantify all steps taken.(23) This finding suggests duration of wear time should receive consideration when designing future validation studies in order to encourage patient retention. Finally, nine out of 47 participants (19%) were unable to be included in an agreement analysis (Kappa) due to the adoption of a constant lying posture.(21)

Discussion

Both commercial and custom made accelerometers placed in isolation on the thigh have demonstrated validity in quantifying time spent in upright or sedentary postures (lying or sitting).(14,16) Distinction between lying and sitting positions has been achieved by placing accelerometers in combination.(11,14,17,19-21). The ability to distinguish between lying and sitting has permitted the ability to identify postural changes between these positions.(14,17) Combinations of placement sites also appear superior in quantifying time in activity.(10) A number of commercial ankle mounted models have demonstrated validity in quantification of step count within older inpatients and adults recovering from critical illness.(22,23) Thigh mounted accelerometers were not valid in elderly medical patients who walked at slow speed. However, placement on an unaffected limb in older patients post hip fracture or stroke

reduced error in step count.(14) Whilst a variety of accelerometers have undergone investigation of their validity, only one study has investigated reliability.(22)

Identification of body position or postural transition

Thigh mounted uniaxial activPAL and multiaxial custom made models have demonstrated validity in quantifying time in sedentary and upright periods.(14,16) Thigh mounted accelerometers are likely to encounter difficulty distinguishing between lying and sitting postures because of the similar horizontal position of the thigh during adoption of both positions. A triaxial activPAL model has demonstrated encouraging results in distinguishing lying from sitting based on detection of thigh rotation.(27) Further research is encouraged to understand if this model can differentiate between these two postures in clinical populations.

A GENEActiv wrist worn model reported fair to moderate epoch by epoch agreement against the uniaxial activPAL for quantification of time in lying or sitting and standing.(18) It is difficult conclude whether it was the GENEActiv that was less successful in posture identification or its placement site when compared to the thigh. The thigh has been reported as an optimal placement site for a triaxial accelerometer in determination of static postures and movement.(28) Others studies have determined placement around the knee to be one of the optimal placement sites for identification of postural transitions due to the active involvement of this body part during these activities.(29)

If differentiation between lying, sitting and standing is clinically necessary, a combination of placement sites permits this. A combination of thigh and sternum(11,14) or thigh and ankle(20, 21) have both demonstrated validity in identification of body position or postural transfers including lying to sitting and sitting to standing. The results section reported that some loss of participants was encountered in some studies due to the distress

caused by wearing the accelerometers.(16) This finding requires consideration in future validation studies as placement at multiple sites may adversely affect compliance.(29)

Identification of activity intensity

A variety of measurement modes within Motion Logger accelerometer models have been investigated.(12,24,25) One study intended to investigate whether a specific activity undertaken within the ICU, for example getting out of bed, could be identified based on the activity intensity quantified by accelerometry alone. (25) This was not possible due to the limited activities undertaken during data collection; predominantly consisting of passive range of motion exercises and rolling. Activity intensity quantified by an accelerometer during particular movements may not be consistent, especially in populations where a variety of methods are employed to assist postural transitions and movement generally.

Two studies using Motion Logger models evaluated correlations between accelerometer derived activity intensity and observation (12) or self-report.(24) Moderate correlations were determined for all measurement modes when compared against observation.(12) Correlations ranged from 0.4 to 0.8 ($p < 0.01$) using self-report as a comparator.(24) Populations differed between both studies, enrolling patients with dementia (12) and following major abdominal surgery.(24) Variability of patients' self-perception of how intensive periods of activity were following recovery from abdominal surgery may have accounted for the wide range of correlations.(24) It could not be determined whether the majority of correlations for individual participants were similar to the $r = 0.48 - 0.50$ values reported when investigating patients with dementia as they were not reported. Confounding variables such as pain or the presence of attachments, including catheter bags or intravenous lines may have increased the perceived intensity of even basic activities such as standing from a chair in some participants. This may account for the broad range of correlations

reported, questioning the efficacy of self-report as a criterion measures in these types of studies and populations.

Multiple placement sites appeared superior to a single site for quantifying time spent in activity.(10) However, 95% limits of agreement (LOA) were wide when reporting the percentage difference in active time between observation and accelerometry (see Table 2). Placement of three accelerometers in combination may also prove cumbersome for patients, adversely affecting compliance.(29)

Quantification of step count

Three ankle mounted commercial models, the Actigraph GT3X+, StepWatch3.0 and AMP331 demonstrated validity in quantification of step count in hospitalised populations who walk at slow speeds.(22, 23) Other studies have reported the ankle to be the optimal placement site to capture walking activities.(31) The Actigraph GT3X+ has a low frequency extension (LFE) data filter; recommended to be activated to increase sensitivity at capturing lower intensity movements.(30) The GT3X+ and LFE setting was found to be valid within older hospitalised populations when quantifying step count.(23) A thigh mounted uniaxial activPAL model was not valid, especially at speeds of $\leq 0.47\text{m/s}$. (14)

Previous reviews and systematic reviews have explored accelerometry use within the ICU, the elderly and stroke populations.(7,32-35) The ‘usefulness’ of the Actigraph GT3X+ in determination of step count within older hospitalised populations was questioned within one of these.(35) All studies identified which investigated this model enrolled community dwelling older adults.(36-38) A more recent study moved its placement site from the hip to the ankle, enrolling a hospitalised population of older adults.(23) The authors found the GT3X+ to be valid in determination of step count within this population, highlighting the

importance of consideration of optimal placement sites when determining the validity of specific accelerometer models.

This systematic review has focused specifically on the validity and reliability of accelerometry to identify body position and quantify purposeful activity within a variety of adult hospitalised populations likely to undertake activity at slow speed and low intensity. It does not restrict its focus to elderly hospitalised populations. This is especially important considering the findings that inactivity in hospital is not exclusive to the elderly. (1) It will assist clinicians in making informed choices regarding selection of the most appropriate model and to understand the validity of the measurement modes inherent within certain commercial models.

Several limitations of this systematic review exist. Small sample sizes of ten or less limit the external validity of some findings.(10, 11, 15, 17, 18, 20) Heterogeneity in activities undertaken, measurement modes, placement sites, epoch lengths, accelerometer designs and data analysis reduced the ability to compare accelerometer models. Validity studies with patients experiencing critical illness have so far been undertaken within the ICU.(22, 25) The validity of accelerometry measurement throughout the whole inpatient rehabilitation continuum for critical illness survivors requires further investigation.

Studies not explicitly stating within their title or abstract an aim to investigate the validity or reliability of the accelerometers used did not progress to full text review. As a result, it is possible that aspects of validity investigation which lay within the text may have been overlooked. A further limitation is the focus on validity investigation within inpatient populations alone. The lack of inclusion of results from other validity studies undertaken within similar community based populations prevented assimilation of other findings which could have borne relevance to the aims of the systematic review.

Commercial and custom made accelerometers have demonstrated validity in identification of body position within the selected hospitalised adult populations. Combinations of placement sites including the thigh and ankle or thigh and sternum permit differentiation between lying, sitting and standing and transitions between these postures in a number of accelerometer models. Commercial AMP331, StepWatch 3.0 and Actigraph GT3X+ ankle mounted models have demonstrated validity in quantification of step count. The AMP331 model has also demonstrated reliability. Research in naturalistic settings is encouraged, permitting the ability to assess whether accelerometers can correctly identify all postures typically adopted by these populations. Future studies should also incorporate methods to evaluate accelerometer reliability.

This systematic review has identified a number of accelerometers which have demonstrated validity within a variety of hospitalised adult populations. Single sited models which accurately identify sedentary (lying or sitting) postures will alert clinicians to patients who are spending the majority of the day inactive, despite being independently mobile. Models mounted in combination which can differentiate between lying and sitting will permit opportunity to quantify the time patients spend out of bed. Ankle mounted models which have demonstrated validity in quantification of step count will permit the clinician to unobtrusively quantify the number of steps taken during the day. The ability to monitor the regularity and duration of mobility periods is also possible. Step count goals agreed between clinician and patient may function as powerful incentives to increase activity in hospital.

Clinical Messages

- Single thigh mounted accelerometers encounter difficulty differentiating between lying and sitting postures
- Combinations of placement sites permit detection of lying, sitting and standing, including transitions between these postures
- Ankle mounted accelerometers have demonstrated validity and reliability in quantification of step count in hospitalised populations who walk at slow speeds

Acknowledgements

Thanks are extended to the reviewers and editor for the detailed and constructive feedback received following initial review of the manuscript.

Competing interests

There are no competing interests to declare by any of the authors.

Funding support

This systematic review received no financial support from any public or commercial funding body.

References

1. Mudge AM, McRae P, McHugh K *et al.* Poor mobility in hospitalized adults of all ages. *Journal of hospital medicine.* 2016;11(4): 289-91.
2. Borges RC, Carvalho CR, Colombo AS *et al.* Physical activity, muscle strength, and exercise capacity 3 months after severe sepsis and septic shock. *Intensive care medicine.* 2015;41(8): 1433-44.
3. Graf C. Functional decline in hospitalized older adults. *The American Journal of Nursing.* 2006;106(1): 58-67.
4. Covinsky KE, Palmer RM, Fortinsky RH *et al.* Loss of independence in activities of daily living in older adults hospitalized with medical illnesses: increased vulnerability with age. *Journal of the American Geriatrics Society.* 2003;51(4): 451-8.
5. Sager MA, Dunham NC, Schwantes A *et al.* Measurement of activities of daily living in hospitalized elderly: a comparison of self-report and performance-based methods. *Journal of the American Geriatrics Society.* 1992;40(5): 457-62.
6. Prince SA, Adamo KB, Hamel ME *et al.* A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *The international journal of behavioral nutrition and physical activity.* 2008;5:56. Available from: <http://doi:10.1186/1479-5868-5-56> [Accessed 16th October 2016]
7. Cheung VH, Gray L, Karunanithi M. Review article (meta-analysis): Review of Accelerometry for Determining Daily Activity Among Elderly Patients. *Archives of Physical Medicine and Rehabilitation.* 2011;92: 998-1014.
8. International classification of functioning, disability and health: Geneva , *World Health Organization.* 2001.

9. Liberati A, Altman DG, Tetzlaff J *et al.* The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Annals Of Internal Medicine.* 2009;151(4): W65-W94.
10. Choquette S, Hamel M, Boissy P. Accelerometer-based wireless body area network to estimate intensity of therapy in post-acute rehabilitation. *Journal of NeuroEngineering and Rehabilitation.* 2008; 5 (20). Available from : doi:10.1186/1743-0030-5-20 [Accessed 29th November 2014]
11. Culhane KM, Lyons GM, Hilton D *et al.* Long-term mobility monitoring of older adults using accelerometers in a clinical environment. *Clinical Rehabilitation.* 2004;18(3): 335-43.
12. Nagels G, Engelborghs S, Vloeberghs E *et al.* Correlation between actigraphy and nurses' observation of activity in dementia. *International Journal of Geriatric Psychiatry.* 2007;22(1): 84-6.
13. Landis JR, Koch GG. The Measurement of Observer Agreement for Categorical Data. *Biometrics.* 1977; 33(1), 159-74
14. Taraldsen K, Askim T, Sletvold O *et al.* Evaluation of a Body-Worn Sensor System to Measure Physical Activity in Older People With Impaired Function. *Physical Therapy.* 2011;91(2): 277-85.
15. Harris N, Britton E, Morrell E *et al.* Evaluation of a single axis accelerometry system for monitoring sit to stand activity in stroke patients. *Clinical Rehabilitation.* 2006;20(7): 637-8.
16. Godfrey A, Conway R, Leonard M *et al.* Motion analysis in delirium: A discrete approach in determining physical activity for the purpose of delirium motoric subtyping. *Medical Engineering and Physics.* 2010;32(2): 101-10.

17. Raymond M, Winter A, Holland AE. Validation of an Activity Monitor in Older Inpatients Undergoing Slow Stream Rehabilitation. *Journal of Physical Activity & Health*. 2015;12(9): 1298-1303.
18. Rowlands AV, Olds TS, Hillsdon M *et al*. Assessing Sedentary Behavior with the GENEActiv: Introducing the Sedentary Sphere. *Medicine & Science in Sports & Exercise*. 2014;46(6): 1235-47.
19. Kramer SF, Cumming T, Churilov L *et al*. Measuring activity levels at an acute stroke ward: Comparing observations to a device. *BioMed Research International*. 2013. Available from: [dx.doi.org/10.1155/2013/460482](https://doi.org/10.1155/2013/460482) [Accessed 29th November 2014]
20. Pedersen MM, Bodilsen AC, Petersen J *et al*. Twenty-four-hour mobility during acute hospitalization in older medical patients. *Journals of Gerontology Series A: Biological Sciences & Medical Sciences*. 2013;68(3): 331-7.
21. Brown CJ, Roth DL, Allman RM. Validation of use of wireless monitors to measure levels of mobility during hospitalization. *Journal Of Rehabilitation Research And Development*. 2008;45(4): 551-8.
22. Edbrooke L, Lythgo N, Goldsworthy U *et al*. Can an accelerometer-based monitor be used to accurately assess physical activity in a population of survivors of critical illness? *Global journal of health science*. 2012;4(3): 98-107.
23. Webber SC, St John PD. Comparison of ActiGraph GT3X+ and StepWatch Step Count Accuracy in Geriatric Rehabilitation Patients. *Journal Of Aging And Physical Activity*. 2016. Webber SC, St John PD. Comparison of ActiGraph GT3X+ and StepWatch Step Count Accuracy in Geriatric Rehabilitation Patients. *Journal Of Aging And Physical Activity*. 2016; 24(3): 451-8

24. Bisgaard T, Kjaersgaard M, Bernhard A *et al.* Computerized monitoring of physical activity and sleep in postoperative abdominal surgery patients. *Journal of Clinical Monitoring and Computing.* 1999;15(1): 1-8
25. Winkelman C, Higgins PA, Chen YK. Activity in the chronically critically ill. *Dimensions of Critical Care Nursing.* 2005;24(6): 281-90.
26. Charlotte L, Edwardson EAHW, Danielle H *et al.* Considerations when using the activPAL monitor in field-based research with adult populations. *Journal of health and sports sciences.* 2016. Available from:
<http://dx.doi.org/10.1016/j.jshs.2016.02.002> [Accessed 26th November 2016]
27. Lyden K, John D, Dall P *et al.* Differentiating Sitting and Lying Using a Thigh-Worn Accelerometer. *Medicine and science in sports and exercise.* 2016;48(4): 742-7.
28. Fortune E, Lugade VA, Kaufman KR. Posture and movement classification: the comparison of tri-axial accelerometer numbers and anatomical placement. *Journal of biomechanical engineering.* 2014;136(5). Available from:
dx.doi.org/10.1115/1.4026230 [Accessed 3rd January 2017]
29. Atallah L, Lo B, King R *et al.* Sensor positioning for activity recognition using wearable accelerometers. *IEEE transactions on biomedical circuits and systems.* 2011;5(4): 320-9.
30. Feito Y, Garner HR, Bassett DR. Evaluation of ActiGraph's low-frequency filter in laboratory and free-living environments. *Medicine and science in sports and exercise.* 2015;47(1): 211-7.
31. Preece SJ, Goulermas JY, Kenney LP *et al.* A comparison of feature extraction methods for the classification of dynamic activities from accelerometer data. *IEEE transactions on bio-medical engineering.* 2009;56(3):871-9.

32. Taraldsen K, Chastin SF, Riphagen II *et al.* Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: a systematic literature review of current knowledge and applications. *Maturitas*. 2012;71(1): 13- 19.
33. Gebruers N, Vanroy C, Truijen S *et al.* Monitoring of Physical Activity After Stroke: A Systematic Review of Accelerometry-Based Measures. *Archives of Physical Medicine & Rehabilitation*. 2010;91(2): 288-97.
34. Verceles AC, Hager ER. Use of Accelerometry to Monitor Physical Activity in Critically Ill Subjects: A Systematic Review. *Respiratory Care*. 2015;60(9): 1330-6.
35. McCullagh R, Brady NM, Dillon C *et al.* A Review of the Accuracy and Utility of Motion Sensors to Measure Physical Activity of Frail, Older Hospitalized Patients. *Journal Of Aging And Physical Activity*, 2016; 24 (3): 465-75.
36. Storti KL, Pettee KK, Brach JS *et al.* Gait speed and step-count monitor accuracy in community-dwelling older adults. *Med Sci Sports Exerc*, 2008; 40(1): 59-64.
37. Barreira TV, Brouillette RM, Foil HC *et al.* Comparison of older adults' steps per day using NL-1000 pedometer and two GT3X+ accelerometer filters. *J Aging Phys Act*, 2013; 21 (4): 402-16.
38. Webber SC., Magill SM, Schafer JL *et al.* GT3X+ accelerometer, Yamax pedometer and SC-StepMX pedometer step count accuracy in community-dwelling older adults. *J Aging Phys Act*, 2014; 22 (3): 334-41.

Table 1: Eligibility criteria

Criterion (PICOS)	Eligibility criteria
Participants	Adult hospital inpatients recovering from acute or critical illness
Intervention	Investigation of an accelerometer (commercial or custom made) to identify or quantify at least one of the following aspects: <ul style="list-style-type: none">• body position (lying, sitting or standing/upright)• postural transition (e.g. sitting to standing)• purposeful activity (general movement or walking)
Comparator	<ul style="list-style-type: none">• Accelerometers being compared against a criterion measure (e.g. observation) for investigation of validity• Devices undergoing repeated measures (test retest) to evaluate reliability.
Outcome	Results of validity or reliability analyses of the accelerometers used within the studies
Study Design	Studies stating a primary or secondary aim was to investigate the validity or reliability of accelerometry measurement

Appendix 1: MEDLINE electronic database search strategy

Search Order	Search terms incorporating Boolean terminology	Article yield
S16	S7 AND S10 AND S15	629
S15	S11 OR S12 OR S13 OR S14	4,918,957
S14	AB hospital* OR AB inpatient* OR AB clinic* OR AB acute* OR AB critical* OR AB intensive OR AB unit* OR AB ICU* OR AB ITU* OR AB HDU* OR AB ward*	4,140,806
S13	TI hospital* OR TI inpatient* OR TI clinic* OR TI acute* OR TI critical* OR TI intensive OR TI unit* OR TI ICU* OR TI ITU* OR TI HDU* OR TI ward*	1,503,819
S12	(MH "Intensive Care+")	19,763
S11	(MM "Inpatients") OR (MH "Hospital Units+")	84,486
S10	S8 OR S9	618,187
S9	TI valid* OR AB valid*	418,426
S8	(MH "Reproducibility of Results+") OR (MH "Validation Studies")	274,884
S7	S1 OR S4 OR S5 OR S6	10,549
S6	TI actigraph* OR AB actigraph*	2,977
S5	TI acceleromet* OR AB acceleromet*	7,277
S4	S2 AND S3	565
S3	(MH "Walking+") OR (MM "Mobility Limitation")	20,579
S2	(MH "Acceleration+")	8,291
S1	(MH "Accelerometry+")	2,162

**Appendix 2: Critical Appraisal Skills Programme (CASP) Cohort study checklist
(Version 31st May 2013)**

File supplied

Figure 1: Flow diagram detailing the article selection process

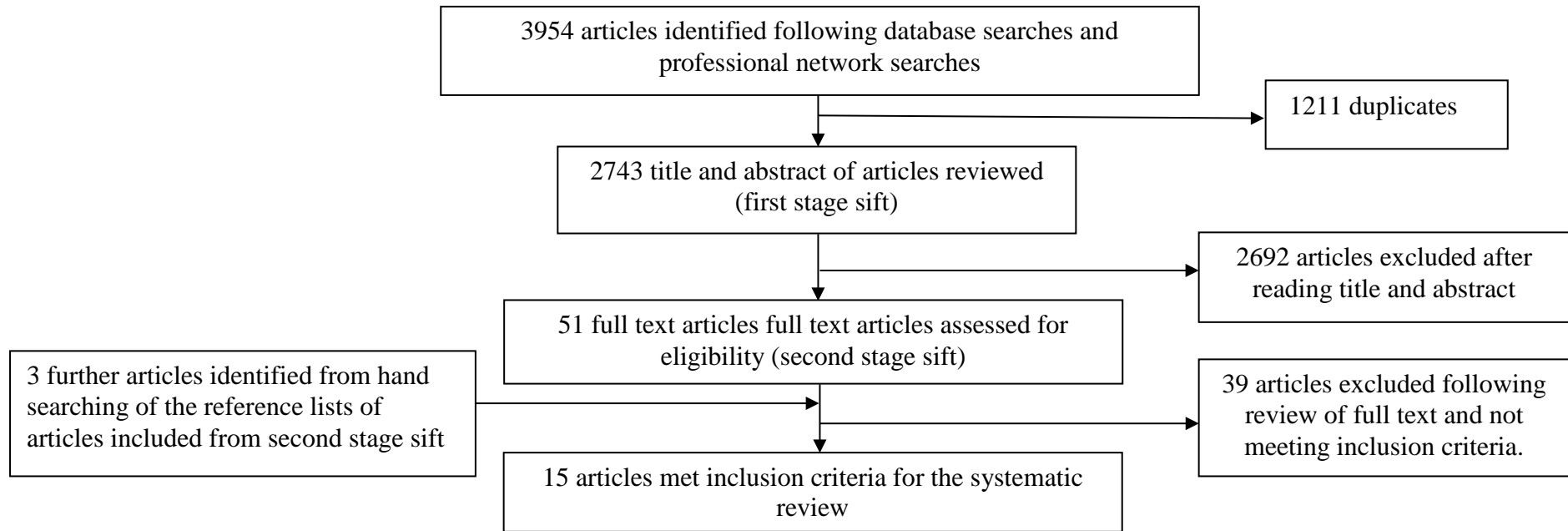


Table 2: Accelerometer models investigated

Accelerometer (epoch used where reported), population (sample size)	Placement	Activity investigated, criterion measure	Findings
Uniaxial activPAL (one second) (14) Uniaxial activPAL (two seconds) (15) <ul style="list-style-type: none"> Inpatient stroke ($n = 14$) older inpatients ($n = 14$), post hip fracture (not hospitalised) ($n = 8$) (14) Acute stroke ($n = 6$) (15) 	Thigh (14,15) Thigh / sternum (14)	Identification of body position / postural transition (14,15) and step count (14) Video recordings (14) Observation (15)	Thigh: <ul style="list-style-type: none"> No misclassification of time in lying/sitting or upright postures. Step count not valid at speed $< 0.47\text{m/s}$. (14) Mean difference in count of 2.3 ± 5.1 sit to stand transfers (95% CI -7.7 to 12.2). Mean number of transfers performed was 46 (range 31-70) (15) Thigh/sternum: <ul style="list-style-type: none"> 100% recognition of lying to sitting/ sit to stand transfers. (15)
Activity Monitoring Pod ‘AMP 331’ (22) Critical illness survivors ($n = 20$)	Ankle	Step count Observation (two observers)	Mean difference (95% LOA): <ul style="list-style-type: none"> Walk 1 0.93 steps (0.39 to 1.48 steps) Walk 2 0.92 steps (0.44 to 1.40 steps) Test retest reliability ($n = 19$) ICC (95% CI) 0.99 (0.99- 1.00)
ADXL202 (one second) (11) Older patients ($n = 5$)	Thigh/ sternum	Identification of body position and activity Observation	<ul style="list-style-type: none"> Best results using ‘best estimate’ approach, using pre-determined threshold angles recorded at both thigh and sternum. Mean percentage agreement for sitting 92%, standing 98%, lying 95%. Detection of dynamic activity 97%. Overall detection of body position and activity 92%
AugmenTech monitors (one second) (20) AugmentTech monitors (20 second) (21) <ul style="list-style-type: none"> Older inpatients (validation component $n = 6$) (20) Older inpatients ($n = 47$) (21) 	Thigh / ankle of same leg	Identification of lying, sitting and standing/walking (20) Time spent in lying, sitting or standing/walking (21) Observation	<ul style="list-style-type: none"> Percentage agreement (mean (range)) for lying 98.3% (90.81-100%), sitting 96.9% (95.28-98.61%) and standing/ walking 93.1% (89.62 - 96.49%). (20) Correlations for time spent in lying: $r = 0.98$, sitting: $r = 0.97$, standing/ walking: $r = 0.91$ ($p < 0.001$). (21) Individual agreement ($n = 38$) $\kappa = 0.28$-0.98 (median $\kappa = 0.92$). κ over all 20 second observations $\kappa = 0.88$ (95% CI 0.878 – 0.886) (21)

Table 2: (continued)

<p>GENEActiv (15 seconds)(18)</p> <p>Acute exacerbation of COPD ($n = 10$)</p>	<p>Wrist</p>	<p>Time spent in sitting/ lying and standing)</p> <p>Uniaxial activPAL</p>	<ul style="list-style-type: none"> • Significantly fewer minutes sitting and more minutes standing ($p < 0.05$) classified by GENEActiv. • Sitting time correlation 0.78 ($p < 0.01$). • Intraindividual epoch agreement (κ) (mean \pm SD) 0.38 ± 0.11 (70% $\kappa > 0.3$)
<p>GT3X+ (one second) (23)</p> <p>Older inpatients ($n = 38$ for hallway walk, $n = 21$ for daily step count)</p>	<p>Hip</p> <p>Ankle</p>	<p>Step count during a hospital hallway walk and daily step count</p> <p>Observation (hand tally counter)</p>	<ul style="list-style-type: none"> • Best results for ankle placement using the low frequency extension (LFE) data filter with ICC (95% CI) of 0.938 (0.870, 0.969) for hallway walk. • Only hip placement used to record daily step count. LFE filter comparable with StepWatch 3.0: StepWatch 3.0 median total steps (IQR) 2740 (2626.0) and GT3X+ 3112 (919.05) ($p > 0.05$)
<p>Motion Logger ('Basic') (30 minutes) (12)</p> <p>Mini Motion Logger (one minute) (24)</p> <p>Motion Logger (one minute) (25)</p> <ul style="list-style-type: none"> • Older adults with dementia ($n = 110$) (12) • Post major abdominal surgery ($n = 12$) (24) • Critically ill in ICU ($n = 20$) (25) 	<p>Wrist</p>	<p>Activity intensity and/ or frequency</p> <p>Observation (12, 25)</p> <p>Self-report (24)</p>	<ul style="list-style-type: none"> • Correlations of $r = 0.48$ to 0.50 ($p < 0.001$) for identification of different activity intensities using three different measurement modes (12) • Mean agreement for perceived intensity of activity of 80% (SD 12%). Individual correlations $r = 0.4$ to 0.8 ($p < 0.001$). (24) • 76% agreement (range 40 - 100%) for frequency of activity and 66% for time in activity (40 - 80%). (25)
<p>Positional Activity Logger 'PAL'2 (three seconds) (17)</p> <p>'PAL2' ('seconds') (19)</p> <ul style="list-style-type: none"> • Older inpatients ($n = 12$) (17) • Inpatient stroke ($n = 26$) (19) 	<p>Above / below the knee</p>	<p>Time spent in lying, sitting, upright or activity/ postural transitions</p> <p>Video recording (17)</p> <p>Observation (19)</p>	<ul style="list-style-type: none"> • 100% agreement for sitting to lying transitions. (17) • Over / underestimation ($\leq 10.5\%$) for sit to stand/ stand to sit transfers. (17) • No difference in time spent in each position ($p = 0.055$ to 0.646). Tendency to overestimate time in lying or overall activity. (17) • ICC (95% CI) for time in lying 0.74 (0.46 - 0.89), sitting 0.68 (0.36 - 0.86) and upright 0.72 (0.43 - 0.88). (19)

Table 2: (continued)

<p>StepWatch 3.0 (three seconds) (23)</p> <p>Older inpatients ($n = 38$ for hallway walk, $n = 21$ for daily step count)</p>	<p>Ankle</p>	<p>Step count during a hospital hallway walk and daily step count</p> <p>Observation (hand tally counter)</p>	<ul style="list-style-type: none"> • ICC (95% CI) for hallway walk of 0.960 (0.924, 0.979). Daily step count compared GT3X+ with LFE (hip placement), no significant differences between both accelerometer models. StepWatch 3.0 median total steps (IQR) 2740 (2626.0) and GT3X+ 3112 (919.05) ($p > 0.05$)
<p>Non-commercial model LIS3LO2AQ (ten seconds) (10)</p> <p>Older inpatients ($n = 5$)</p>	<p>Hip</p> <p>Hip / wrist / ankle</p>	<p>Time spent in activity</p> <p>Observation</p>	<ul style="list-style-type: none"> • Best results when placed in combination: $r = 0.93$ ($p \leq 0.001$); ICC per subject 0.65 to 0.98 ($p \leq 0.01$). • Single / combination of placement sites tended to underestimate active time. Best results for combination of placement sites with mean (SD) of -8.6% (17.9%), with 95% LOA -43.7% to 26.5%. • Results worst for active time during antalgic gait therapy: ICC (95% CI) for single placement 0.29 (CI -0.42 to 0.78) and 0.32 (CI -0.39 - 0.79) for combination.
<p>Non-commercial model (raw data) (16)</p> <p>Hospital inpatients with/ without delirium ($n = 40$)</p>	<p>Thigh</p>	<p>Time spent in lying/sitting, standing and walking</p> <p>activPAL</p>	<ul style="list-style-type: none"> • Percentage agreement for time spent in sitting/lying: 99%, standing: 99%, walking 97%.