Highlights

- Wearable trackers have acceptable accuracy, especially for measuring step counts, moderate to vigorous physical activity MVPA, ECG and HR heart rate, and for electrocardiography, but not for measuring respiratory rate (RR).
- Most older adults have reported ease of use and also demonstrated high-level adherence over daily long-term use.
- Methodological designs for data collection were have been heterogeneous and currently there are no standardised methods for quantifying data from wearable devices in older adults. As such, frameworks and/or guidelines are needed to support the ongoing use of wearable trackers to capture the physical activity of older adults.

Data management and The use of wearable trackers in by older adults and data management: A systematic review.

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Abstract

Background: Wearable trackers as research or clinical tools are increasingly used to support the care of older adults, due to their practicality in self-monitoring and potential to promote healthy lifestyle behaviours. However, there is limited understanding of appropriate data collection methods and analysis for methods in different contexts still exists.

Aim: To summarise evidence on wearable data generation and management in older adults, focusing on physical activity (PA), electrocardiogram (ECG), and vital signs monitoring. In addition to examine the accuracy and utility of incorporating wearable trackers into the care of older people.

Methods: A systematic search of CINAHL, MEDLINE, PubMed and a manual search were conducted. Twenty studies targeting on the use of wearable trackers use by in older adults met the inclusion criteria.

Results: Methodological designs for data collection and analysis were heterogeneous, with diverse definitions of wear and no-wear time, the number and type of valid days, and proprietary algorithms. Wearable trackers had adequate accuracy for measuring step counts, moderate to vigorous physical activity (MVPA), ECG and heart rate (HR), but not for respiratory rate. Participants reported ease of use and had high-level adherence over daily long-term use. Moreover, wearable trackers encouraged users to increase their daily PA level of physical activity and decrease waist circumference, facilitating atrial fibrillation (AF) diagnoses and predicting length of stay.
Conclusion: Wearable trackers are multi-dimensional technologies offering a viable and promising approach for sustained and scaled monitoring of older people’s health. Frameworks and/or guidelines, including standards for the design, data management and application of use specifically for older adults, is required to enhance validity and reliability.

Keywords
older, physical activity, wearable, sensor, monitor, tracker

1. Introduction

Aging populations with their high prevalence of chronic diseases have a significant impact on the healthcare system of any country. Fortunately, extraordinary advances in wearable tracker technology promote the potential to meet the demands of the healthcare system and facilitate the care of older adults. Notably, a wide array of commercial wearable trackers have recently appeared on the market. These trackers are inexpensive and are equipped with advanced functionality that utilises proprietary sensor technologies and data processing formulas to offer users a real-time assessment of their physiological, physical, psychological, and behavioural data [1, 2]. This includes data on heart rate (HR), blood pressure (BP), respiration rate (RR), electrocardiogram (ECG), and physical activity (PA) levels [1, 2]. Therefore, wearable trackers offer a practical alternative for everyday monitoring of PA, ECG and vital signs [2].

Although older adults perceive wearable trackers as beneficial and acceptable [3], the fast advances in wearable technology and the diverse methods of data processing have resulted in a lack of
standards of practice for monitoring calibration and validation and field application, such as for the objective monitoring of PA [4]. Specifically, how to collect, calibrate, process, and use data from wearable trackers continues to be one of the critical challenges when using these devices [4]. It is also important to note that accelerometry assumptions for the selection of cut-points and data analysis are not standardised across research protocols [5, 6]. Most research guiding accelerometry data analysis methods is derived from studies that involved children and young adults [5, 7, 8], and there is limited research on accelerometry data in older adults. Consequently, the primary aim of this paper is to present a systematic review of wearable data generation and management in older adults focusing on PA, ECG and vital signs monitoring (i.e., HR, BP, and RR). The secondary aim is to examine accuracy and the utility of incorporating wearable trackers into the care of older adults.

2. Methods

Both an electronic database search of CINAHL, MEDLINE, PubMed and a manual search were performed to identify the relevant articles. The search included the following terms: (1) ‘sensor’ or ‘monitor’ or ‘device or ‘tracker’, and (2) ‘wearable’. We limited our search to adults aged 65 years and older using relevant Medical Subject Headings. We included studies which met the following criteria: (1) published in English and targeted older population (i.e., ≥ 65 years old), (2) specifically investigated health-related wearable trackers; (3) study outcome focused on PA (i.e., active minutes and step counts), ECG, and vital signs monitoring. We excluded studies that primarily involved traditional pedometers or research grade trackers such as the ActiGraph accelerometer. We also excluded studies that mainly examined ‘gait’ and ‘falls’ because a recent published review has already summarised the current literature on older adult’s gait assessment through use of wearables.
Using the above keywords, the initial search retrieved 485 studies of which 20 were eligible for full review (Figure 1). Any disagreements about inclusion were resolved through conversation between two team members (MA and RG). The Critical Appraisal Skills Programme (Cohort Study) Checklist was used to assess the quality of the reviewed studies. On assessment, although five of the studies met a minimum 80% of the evaluation criteria, the majority of the included studies were of poor to moderate quality. The findings of the reviewed studies were extracted manually and summarised in tables.

3. Results

3.1 Overview of the wearable trackers included in the reviewed studies

Twelve different wearable trackers and 20 studies were included in this review (Table 1). Trackers include: ADAMO Care Watch, Fitbit Charge HR, Fitbit Flex, Fitbit One, Fitbit Zip, HealthPatch MD, iRhythmZio, Jawbone UP, MagIC, Misfit Shin, Nike+FuelBand, and Polar A300. The most commonly used wearable trackers across all reviewed studies were Fitbit One (n=7) and Fitbit Charge HR (n=4). It should be noted, there is a high turnover rate of wearable trackers available on the market so that one of the trackers reviewed, Jawbone UP, discontinued in 2011.

3.2 Data acquisition in the reviewed studies

The sample characteristics of the 20 included studies, wearable tracker name, data collection method, and analysis protocols are summarised in Table 2. The majority of the reviewed studies had PA as their focus (n=15), followed by ECG (n=3) and then vital signs (n=2).

The sample sizes ranged from eight to 2659 (total 3741 participants). The overall mean age was 69 years and almost all studies (n=18) included both males and females, with the minority of
participants, females (42%). The diagnoses varied widely among the studies, but almost half the studies (n=8) included participants who had or were at high risk of cardiovascular disease. Twelve studies were conducted in a free-living environment, 6 studies were conducted in a controlled environment, and 2 studies utilised both controlled and free-living environments. The wearable trackers were placed on the wrist (n=12), waist (n=8), chest (n=4), ankle (n=2) and pocket (n=2).

Data collection, and analysis protocols were heterogeneous. The overall duration of the data collection ranged from two minutes to eight months. Among the studies conduction in a free-living environment, the tracker wear time was during all waking hours (i.e. valid day with ≥10 wear hours/day) in three studies, and for 24 hours in 11 studies. The definition of wear time varied among the reviewed studies. For instance, a cut-off threshold of 150 minutes [10] or 60 minutes [11] of continuous zero data from the wearable tracker was deemed as being non-wear data. Participants were required to wear the tracker for at least seven consecutive wearing days in over half of the included studies (11 of 20); at least five consecutive wearing days in one study; at least four consecutive wearing days including weekend days and weekdays in one study; with the remaining studies (7 of 20) including three consecutive wearing days or less. The algorithms and classifiers used for the feature computation varied among the reviewed studies. The majority of studies utilised proprietary algorithms that set its sampling interval at 60 seconds, but the shorter epochs (15 seconds) were reported in one study. Similarly, almost all of the studies used proprietary algorithms (not known to the authors, as the formulas are proprietary to the company) to define the cut point of the measured outcomes; for example, minutes of moderate to vigorous physical activity (MVPA). Two studies utilised clinicians (e.g., cardiologists) to manually score and classify the data.

3.3 Data accuracy: Outcomes of the reviewed studies in terms of reliability and/or validity
Twelve [1,10,23,26-29,31-33,38-39] of the 20 reviewed studies targeted validity and/or reliability (Table 3). Overall, eight studies examined the validity and/or reliability of different wearable trackers in measuring step counts [10,26-29,32,33]. The outcomes of these studies supported the validity and reliability of the wearable trackers in tracking step counts but noted that walking at slow speeds and wrist-worn trackers may affect their accuracy. Two studies highlighted the capabilities of wearable trackers in accurately tracking active minutes of PA, especially MVPA [30,31]. Similarly, two studies showed wearable trackers had acceptable validity for measuring HR [38,39]. One study found that wearable trackers provide an accurate ECG reading [23]. However, one study warned against the use of wearable trackers for measuring respiratory rate as its accuracy was outside acceptable limits [38].

3.4 Data utility: Outcomes of the reviewed studies regarding the clinical benefits of wearable trackers and their acceptability

Eight of the 20 reviewed studies targeted the data utility of wearable trackers (Table 4). Four [24-25,34,37] of the eight studies centred focused on the usefulness of wearable trackers as a measure of clinical outcomes, three studies [3,11,34] focused on the participants’ acceptance, adoption or abandonment of wearable trackers, one study [36] included both of the aforementioned aims, and one study examined the usefulness of wearable trackers as a motivational tool for PA behaviour change.

Regarding the clinical benefits, one study found a significant relationship between steps taken, length of stay, and dismissal disposition [37]. One study showed self-monitoring of PA using wearable trackers decreased waist circumference significantly [35], and two studies highlighted that wearable self-applied ECG patches facilitated AF diagnoses [24,25]. Moreover, one study [36] showed that feedback from a PA wearable tracker motivates behaviour change. Regarding the
wearable tracker acceptability, three \([3,11,35]\) studies found that participants reported the wearable trackers were easy to use and they also had high-level adherence over daily long-term use. However, one study \([34]\) found that abandonment-related issues influencing daily long-term use of wearable trackers involved the collection of inaccurate data, time wasting, and wearing discomfort.

4. Discussion

Our results showed that overall, wearable trackers had adequate accuracy, especially for measuring step counts, MVPA, ECG and HR, but not for measuring RR. Moreover, most participants reported ease of use and also demonstrated high-level adherence over daily long-term use. Some participants, however, found the wearable trackers very difficult to use, and it is therefore important to consider the usability, comfort and feasibility of the trackers for older participants. Importantly, wearable trackers have become standard objective methods for assessing health outcomes such as PA. They have also demonstrated the usefulness of wearable technology for encouraging users to increase their daily PA level and to decrease their waist circumference, facilitating AF diagnoses and predicting hospital length of stay \([24, 35, 37]\). Therefore, wearable trackers may be promising for use among this cohort to help in diagnosing, monitoring and encouraging sustained changes in healthy behaviours such as PA.

Importantly, our findings highlighted that methodological designs for data collection were heterogeneous and that there is no standardised method for quantifying data from wearable devices in older adults. Given the lack of a universally accepted definition \([12, 13]\) for data collection and analysis of wearable trackers, future research is needed to produce specific assumptions for this work that is most applicable for older people, particularly accounting for their physical capacity. It is vital to standardise tracker placement and the number and type of valid days needed to achieve acceptable validity and reliability to ensure comparability across study outcomes. For example, the
most common practice for PA measurement is a minimum of four days of valid data for analysis, including weekend days [14]. It is also critical to standardise the definitions of wear time and no-wear time. For instance, the criteria for no-wear time most commonly applied is removal of the tracker for 60 minutes or more of continuous zeros, with allowance of 1-2 minutes [15], but 90 minutes has been proposed for older people with limited mobility [16].

Of note, almost all the review studies relied on tracker proprietary algorithms, which set the sampling interval at different short or long epochs. Thus, a standardised algorithm or cut points to define an outcome (e.g. MVPA) are critical to support the tracker validity and reliability. A considerable amount of time and effort has been invested by researchers and manufacturers to make sure the algorithms in wearable trackers accurately measure clinical outcomes such as PA level. However, this pursuit presents numerous issues and challenges for stakeholders; namely, clinicians, researchers, tracker manufactures and patients [1]. Algorithms to aggregate raw tracker data into operational variables are regularly modified and frequently not available [17]. For instance, the Fitbit manufacturer recently modified the algorithm used to count active minutes without notification. All stakeholders are therefore eager to ensure tracker accuracy facilitates the precise monitoring of PA and other important health outcomes. Hence, wearable tracker manufacturers need to ensure the algorithm delivers high-level accuracy equal to research-grade accelerometers (e.g. Actigraph) and to inform stakeholders when modifications to the algorithms occur to uphold their trust.

There are difficulties in ensuring the literature remains up to date on current models due to the frequency of new releases of wearable trackers [17]. Moreover, consideration must be given to the high turnover rate of wearable trackers in the market and that some trackers are no longer produced (e.g. Jawbone). The wide range of tracker features (e.g. step counts, active minutes and energy expenditure) also complicates the practicality and accuracy of wearable trackers in
measuring health outcomes such as all dimensions of PA [17]. Uncertainties around the ownership of data and therefore accessibility to the data for research purposes also presents challenges to review boards in institutions as essentially it is data collection from third parties [1, 18]. In addition, there are issues regarding data structure and quality due to tracker manufacturers not sharing the data or their data collection methods with researchers [1, 18, 19]. Lastly, given we live in the digital personal health era, issues may emerge over data privacy [1, 18]. Hence, future research is needed to generate studies on privacy policies of wearable trackers and also to review federal and state legislation related to data protection.

Notably, the acceptable level of inaccuracy varied and often was not clearly defined. Indeed, even in the literature there is no widely agreed definition of acceptable degree of error for PA wearable trackers. Acceptable measurement error for PA under controlled conditions or for research purposes is suggested to be within ±3% [20, 21], and under free-living conditions is within ±10% [20, 21]. Other literature advises that errors of less than 20% have acceptable validity for clinical purposes [22]. Depending upon the work being studied and the purposes of the validation study, it is important for future studies with elderly participants to standardise the analysis methods in order to guide validity interpretation for wearable trackers and to highlight the different validity criteria between the tested and criterion measures for clinical purposes compared to research purposes.

Finally, it is worth noting that gender differences are likely, yet seldom examined. Only one study [30] analysed data separately by gender using Fitbit-Flex noted that male participants recorded significantly more steps and higher MVPA minutes than their female counterparts.

Several limitations need to be acknowledged. We searched only a limited number of databases and reviewed articles published in English only so some studies may have been missed. Also, there is insufficient reporting for the accelerometry assumptions in several of the reviewed studies, creating difficulty for fully evaluating the accelerometer protocol.
5. Implications for practice and future research

The findings of this review have a number of important implications:

1. Wearable trackers are generally valid, reliable and/or feasible when tracking step counts, MVPA, ECG and HR in aging populations. Thus, trackers may be ideal to help in diagnosing, measuring, monitoring and/or motivating in this population cohort.

2. There needs to be a framework and/or guidelines and a standardised method for the collection and analysis of wearable tracker data specifically for older people’s physical capacity.

3. Manufacturers of trackers must ensure the tracker algorithm delivers a high level of accuracy similar to a research-grade accelerometer.

4. Although there is extensive validity and reliability research available, there are no studies examining the responsiveness of wearable trackers. Thus, further research is needed to develop evidence-based responsiveness.

6. Conclusion

A definitive recommendation for a wearable tracker or method of data collection and analysis could not be made due to lack of strong evidence as the majority of primary studies used proprietary algorithms and there is no way to access the primary data. However, wearable trackers are generally valid, affordable and useful for monitoring a number of clinical outcomes such as PA, ECG and vital signs in real-time, and for accounting for day-to-day variations. This encourages more accurate and personalised clinical intervention for older people. Wearable trackers are promising tools for clinicians to manage the care of older people, however, the validity and reliability of wearable
trackers are impacted by a number of factors including fast-paced technological developments, frequent updates to algorithms by manufacturers, and an absence of a consensus protocol for data collection and analysis. Future research is encouraged to develop guidelines and standards for the design and application of wearable technology in aging populations.

**Contributors**

Muaddi Alharbi contributed to the concept, design and conduct of the review, analysis and writing of the manuscript.

Nicola Straiton contributed to the concept and design of the review, and writing of the manuscript.

Sidney Smith contributed to the analysis and writing of the manuscript.

Lis Neubeck contributed to the analysis and writing of the manuscript.

Robyn Gallagher contributed to the concept and design of the review, analysis and writing of the manuscript.

**Conflict of interest**

The authors declare that they have no conflict of interest.

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**Disclosures**

None.
Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.

Provenance and peer review

This article has undergone peer review.

References


Figure 1. Search Strategy

Identification
- Records identified through database and hand searches
  - n = 485

Screening
- Records excluded after title and abstract screening
  - n = 445

Eligibility
- Full-text articles assessed for eligibility
  - n = 40
  - Full-text articles excluded
    - n = 20

Included
- Studies included
  - n = 20
<table>
<thead>
<tr>
<th>Tracker</th>
<th>Released date</th>
<th>What is measured</th>
<th>Software</th>
<th>Battery life</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAMO Care Watch</td>
<td>2010</td>
<td>Steps, distance, calories, active minutes</td>
<td>On screen summary online-feedback, also phone apps</td>
<td>21 days</td>
</tr>
<tr>
<td>Fitbit Charge HR</td>
<td>Jan 2015</td>
<td>Steps, distance, calories, active minutes, sleep, HR</td>
<td>On screen summary online-feedback, also phone apps</td>
<td>5 days</td>
</tr>
<tr>
<td>Fitbit Flex</td>
<td>May 2013</td>
<td>Steps, distance, calories, active minutes, sleep</td>
<td>Online-feedback, also phone apps</td>
<td>7–10 days</td>
</tr>
<tr>
<td>Fitbit One</td>
<td>Sep 2012</td>
<td>Steps, distance, calories, active minutes, sleep</td>
<td>On screen summary online-feedback, also phone apps</td>
<td>14 days</td>
</tr>
<tr>
<td>Fitbit Zip</td>
<td>May 2013</td>
<td>Steps, distance, calories, active minutes, sleep</td>
<td>Online-feedback, also phone app</td>
<td>4–6 months</td>
</tr>
<tr>
<td>HealthPatch MD</td>
<td>Jan 2015</td>
<td>Single-Lead ECG, HR, HR Variability, vital signs, fall detection, steps</td>
<td>Online-feedback, also phone apps</td>
<td>3-5 days</td>
</tr>
<tr>
<td>iRhythmZioXT</td>
<td>Jan 2011</td>
<td>Single-Lead ECG, HR</td>
<td>Online-feedback, also phone apps</td>
<td>14 days</td>
</tr>
<tr>
<td>Jawbone UP</td>
<td>Nov 2011</td>
<td>Steps, calories, distance, sleep</td>
<td>Online-feedback, also phone apps</td>
<td>10 days</td>
</tr>
<tr>
<td>(Note: Dec 2011 discontinued)</td>
<td></td>
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<tr>
<td>MagIC: a textile-based wearable system</td>
<td>April 2009</td>
<td>ECG, respiratory frequency and motion</td>
<td>Online-feedback, also phone apps</td>
<td>3 days</td>
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<tr>
<td>Misfit Shine</td>
<td>Dec 2013</td>
<td>Steps, distance, calories, active minutes, sleep</td>
<td>Online-feedback, also phone apps</td>
<td>4-6 months</td>
</tr>
<tr>
<td>Nike+ FuelBand</td>
<td>Nov 2013</td>
<td>Steps, calories</td>
<td>Online-feedback, also phone apps</td>
<td>4 days</td>
</tr>
<tr>
<td>Polar A300</td>
<td>Feb 2015</td>
<td>Steps, distance, calories, active minutes, sleep, HR</td>
<td>On screen summary online-feedback, also phone apps.</td>
<td>26 days</td>
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<td>Wearable locations</td>
<td>Measure(s) tested</td>
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<tr>
<td>Di Rienzo et al.</td>
<td>N = 50 CR patients Age: 67 Female: 0</td>
<td>MagiC: a textile-based wearable system</td>
<td>Chest</td>
<td>Cardiac rhythm and arrhythmic events</td>
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<tr>
<td>Italy</td>
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<tr>
<td>Steinhubl et al.</td>
<td>N = 2659 at risk of AF Age: 73 Female: 1026 (39%)</td>
<td>iRhythmZio</td>
<td>Chest</td>
<td>ECG patch facilitated AF diagnosis</td>
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<tr>
<td>USA</td>
<td></td>
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<tr>
<td>Turakhia et al.</td>
<td>N = 75 at risk of AF Age: 70 Female: 0 (0%)</td>
<td>iRhythmZio</td>
<td>Chest</td>
<td>ECG patch facilitated AF diagnosis</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Participants</td>
<td>Age</td>
<td>Gender</td>
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<tr>
<td>Magistro et al.</td>
<td>Italy</td>
<td>N = 20 older participants Age: 75 Female 10 (50%)</td>
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<tr>
<td>Burton et al.</td>
<td>Australia</td>
<td>N = 31 older participants Age: 74 Female 20 (65%)</td>
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<tr>
<td>Paul et al.</td>
<td>Australia</td>
<td>N = 32 older participants Age: 68 Female: 20 (63%)</td>
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<tr>
<td>Simpson et al.</td>
<td>Canada</td>
<td>N = 42 older adults Age: 72 Female: 32 (74%)</td>
<td></td>
<td></td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>Sample Size</td>
<td>Participants</td>
<td>Age (years)</td>
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<tr>
<td>Alharbi et al.</td>
<td>Australia</td>
<td>N = 48 CR patients</td>
<td>66:23 (48%)</td>
<td>66</td>
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<tr>
<td>Boeselt et al.</td>
<td>Germany</td>
<td>N = 20</td>
<td>66:3 (15%)</td>
<td>66</td>
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<tr>
<td>Floegel et al.</td>
<td>USA</td>
<td>N = 99 older participants</td>
<td>79:25 (71%)</td>
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<tr>
<td>Thorup et al.</td>
<td>Denmark</td>
<td>N = 24</td>
<td>67:2 (8%)</td>
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<td>Farina et al.</td>
<td>UK</td>
<td>N = 25</td>
<td>73</td>
<td>73</td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>N =</td>
<td>Age</td>
<td>Female</td>
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<tr>
<td>Speier et al.11</td>
<td>USA</td>
<td>200</td>
<td>65</td>
<td>NR</td>
</tr>
<tr>
<td>Fausset et al.34</td>
<td>USA</td>
<td>8</td>
<td>65</td>
<td>(50%)</td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>Sample Size</td>
<td>Age (years)</td>
<td>Gender (% Female)</td>
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<tr>
<td>McMahon et al.</td>
<td>USA</td>
<td>N = 95 older adults</td>
<td>Age: 70</td>
<td>Female: 71 (75%)</td>
</tr>
<tr>
<td>O’Brien et al.</td>
<td>USA</td>
<td>N = 34 older adults</td>
<td>Age: 74</td>
<td>Female: 22 (65%)</td>
</tr>
<tr>
<td>Kanai et al.</td>
<td>Japan</td>
<td>N = 55 inpatients with ischaemic stroke</td>
<td>Age: 65</td>
<td>Female: 28 (51%)</td>
</tr>
<tr>
<td>Cook et al.</td>
<td>USA</td>
<td>N = 149 postop. cardiac surgical patients</td>
<td>Age: 68</td>
<td>Female: 66 (44%)</td>
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<td>Vital signs</td>
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<tr>
<td>Study</td>
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<td>Sample Size</td>
<td>Age</td>
<td>Sex</td>
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<tr>
<td>Kroll et al.</td>
<td>Canada</td>
<td>N = 50 ICU patients</td>
<td>Age: 65</td>
<td>Female: 24 (48%)</td>
</tr>
</tbody>
</table>

**Notes:**
- CR = cardiac rehabilitation; ECG = Electrocardiography; PA = physical activity; AF = atrial fibrillation; LOS = length of stay; ICU = intensive care unit; METs = metabolic equivalent tasks; NR = not reported; h = hours; m = minutes; s = seconds; Hz = hertz
<table>
<thead>
<tr>
<th>Authors</th>
<th>Data collection settings/methods</th>
<th>Data comparison time/distance</th>
<th>Wearable tracker</th>
<th>Measure(s) tested</th>
<th>Cross-validation measure</th>
<th>Main conclusions</th>
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<tr>
<td>Magistro et al.²⁶</td>
<td>Controlled</td>
<td>Procedure took 60m</td>
<td>ADAMO Care Watch</td>
<td>Steps</td>
<td>Steps observed and counted with a manual tally counter</td>
<td>ADAMO Care Watch demonstrated highly accurate measurements of steps count in all activities, particularly walking at normal and slow speeds</td>
</tr>
<tr>
<td>Burton et al.²⁷</td>
<td>Controlled and free-living</td>
<td>7 days; direct observation on day 1 and 7</td>
<td>Fitbit Flex</td>
<td>Steps</td>
<td>Visual step count (video recording) GENEactiv accelerometer</td>
<td>Good reliability and validity of the Flex and ChargeHR, however both trackers underestimated step count in the laboratory environment</td>
</tr>
<tr>
<td>Breteler et al.²⁸</td>
<td>Controlled</td>
<td>1–3 days; 24h</td>
<td>Health Patch MD</td>
<td>Respiratory and heart rate</td>
<td>XPREZZON: ICU grade’ patient monitoring system.</td>
<td>Accurate measurement of HR, but not for respiratory rate</td>
</tr>
<tr>
<td>Kroll et al.²⁹</td>
<td>Controlled</td>
<td>One day; 24h</td>
<td>Fitbit Charge HR</td>
<td>HR</td>
<td>BedMaster-EX, Excel Medical, Jupiter: ICU bedside continuous ECG monitors</td>
<td>Tracker–derived HRs were slightly lower than those derived from continuous ECG monitoring in real-world testing and not as accurate as pulse oximetry- derived HRs</td>
</tr>
<tr>
<td>Di Rienzo et al.³⁰</td>
<td>Controlled</td>
<td>60m for each participant</td>
<td>MagIC: a textile-based wearable system</td>
<td>Cardiac rhythm and arrhythmic events</td>
<td>Fukuda Denshi telemetric ECG (mod DS 5700, Tokyo, Japan); Traditional ECG tracker:</td>
<td>In static condition MagIC accurate in monitoring cardiac rhythm and arrhythmic events and comparable to that obtained by a traditional one-lead ECG recorder. During</td>
</tr>
</tbody>
</table>
With remaining 20 patients, ECGs were performed for 36 minutes during physical rehab. sessions according to protocol: at rest (4 minutes lying, 1 minute standing), during mild calisthenic PA (10 minutes), while pedalling a cycloergometer (15 minutes) and during a 6MWT.

**Paul et al.**<sup>28</sup>  
**Controlled and free-living**  
Wore trackers simultaneously during a 2MWT and then during free-living activities  
2 meters for each participant  
7-day; during waking hours  
Fitbit One  
Steps  
Fitbit Zip  
Visual step count  
(2MWT)  
Fitbit accurately tracked steps during the 2MWT. There was strong agreement between Fitbit and ActiGraph counted steps.

**Simpson et al.**<sup>29</sup>  
**Controlled**  
Participants walked a distance of 15 meters for 8 different walking trials  
During a single testing session  
Fitbit One  
Steps  
Visual step count  
(video recording)  
Fitbit accurately captured steps at slow speeds when placed at the ankle.

**Alharbi et al.**<sup>30</sup>  
**Free-living**  
Wear both trackers simultaneously during free-living activities  
4 consecutive days (two weekend days and two weekdays) during waking hours  
Fitbit Flex  
Steps  
MVPA  
ActiGraph  
Fitbit- is a valid, reliable and alternative tracker for activity monitoring specific to predicted attainment of PA guideline recommendation for step counts and minutes of MVPA.

**Boeselt et al.**<sup>31</sup>  
**Free-living**  
Wear at all times during free-living activities  
3 consecutive days; 24 hours  
Polar A300  
Calories, daily activity time (h) and METS  
Bodymedia SWA  
Polar tracker equivalent to SWA for assessment of PA time, step count and calorie consumption in COPD patients.

**Floegel et al.**<sup>32</sup>  
**Controlled**  
During a single testing session  
Fitbit One  
Steps  
Fitbit Flex  
StepWatch  
StepWatch, Fitbit One, and Jawbone UP.
Instructed to walk at self-selected pace along an unobstructed 100 metre predetermined, flat marked route at their respective community centre location.

Thorup et al.\textsuperscript{33}
Free-living
Wear at all times during free-living activities
1day; 24h (during hospitalisation) and 4 weeks; 24h (thereafter at home mean 28.2, range 26–31)
Fitbit Zip
Steps
Shimmer3
A speed of 3.6 km/h or higher is required for acceptable accuracy in step measurement using Zip. Inaccuracies directly related to slow speeds, and thus for patients with cardiac disease who walk at a slow pace.

Farina et al.\textsuperscript{10}
Free-living
Wear the trackers during waking hours (except for water-based activities)
7 consecutive days; during waking hours
Misfit Shine
Fitbit Charge HR
Steps
Actigraph and NL2000
Compared to the ActiGraph GT3X+, the waist-worn Misfit Shine had highest agreement. Wrist-worn trackers showed poorer agreement to reference trackers.

MWT = minute walk test; PA = physical activity; HR = heart rate; LOS = length of stay; ECG = electrocardiography; AF = atrial fibrillation; ICU = intensive care unit; IHD = ischemic heart disease; h = hours; m = minutes; Sensewear = SWA
Table 4: Data utility: Outcomes of the reviewed studies regarding the clinical benefits of wearable trackers and their acceptability

<table>
<thead>
<tr>
<th>Authors</th>
<th>Research Focus</th>
<th>Objectives</th>
<th>Wearable tracker</th>
<th>Main conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speier et al.</td>
<td>Acceptance, adoption or abandonment</td>
<td>Evaluate adherence rates using consumer-grade continuous-time HR and activity tracker over 90 days in a group of patients with IHD</td>
<td>Fitbit Charge HR</td>
<td>Using continuous-time activity trackers with HR monitors can be effective in a telemonitoring application, as patients had a high level of adherence (90% median usage) and low attrition (0.09% decrease per day) over a 90-day period.</td>
</tr>
<tr>
<td>Fausset et al.</td>
<td>Acceptance, adoption or abandonment</td>
<td>Attitudes and usability issues were assessed and evaluated within a technology acceptance framework the Unified Theory of Acceptance and Use of Technology</td>
<td>Fitbit One Nike+ FuelBand</td>
<td>Initial attitudes were positive, but after using the tracker for two weeks, attitudes were mixed. 3 participants indicated they would continue using the tracker; whereas, 5 would abandon the tracker and described several issues including inaccurate data collected, wasting time, and uncomfortable to wear.</td>
</tr>
<tr>
<td>McMahon et al.</td>
<td>Acceptance, adoption or abandonment</td>
<td>To assess short and long-term experiences of Fitbit One in terms of acceptance, ease-of-use, and usefulness: domains in the technology acceptance model.</td>
<td>Fitbit One</td>
<td>91% agreed or strongly agreed that the tracker was easy to use, useful &amp; acceptable both 10 weeks and 8 months after enrolling in the study. Ratings slightly dropped between these time points in all survey domains: ease-of-use, usefulness and acceptance</td>
</tr>
<tr>
<td>O’Brien et al.</td>
<td>Acceptance &amp; wearable trackers as useful measure of clinical outcomes</td>
<td>To evaluate the feasibility and utility of activity tracker use among older adults for monitoring activity, improving self-efficacy, and health outcomes</td>
<td>Nike Fuel</td>
<td>Participants found activity trackers easy to use, experienced a significant decrease in waist circumference. However no change in steps taken, calories burned, and self-efficacy</td>
</tr>
<tr>
<td>Kanai et al.</td>
<td>Wearable trackers as a motivator of PA behaviour change</td>
<td>To evaluate the effect of accelerometer-based feedback on physical activity in hospitalized patients with ischemic stroke</td>
<td>Fitbit One</td>
<td>Exercise training combined with accelerometer-based feedback effectively increased PA in hospitalized patients with ischemic stroke</td>
</tr>
<tr>
<td>Cook et al.</td>
<td>Wearable trackers as useful measure of clinical outcomes</td>
<td>Examine an activity tracker to measure PA during hospital recovery after cardiac surgery.</td>
<td>Fitbit One</td>
<td>There was a significant relationship between the number of steps taken in the early recovery period, length of stay, and dismissal disposition</td>
</tr>
<tr>
<td>Steinhubl et al.</td>
<td>Wearable trackers as useful measure of clinical outcomes</td>
<td>To determine effect of self-applied wearable ECG patch in detecting AF and the clinical consequences</td>
<td>iRhythmZio</td>
<td>Among individuals at increased risk for AF, use of home-based self-applied ECG patch facilitated AF diagnosis</td>
</tr>
<tr>
<td>Turakhia et al.(^2)</td>
<td>Wearable trackers as useful measure of clinical outcomes</td>
<td>Screening for AF using continuous ambulatory ECG monitoring can detect silent AF in asymptomatic patients with known risk factors</td>
<td>iRhythmZio Tracker is feasible, with AF detected in 1 in 20 subjects with up to 2 weeks of monitoring. Also detected sustained atrial tachycardia and AF in 1 in 9 subjects</td>
<td></td>
</tr>
</tbody>
</table>

PA = physical activity; HR = heart rate; LOS = length of stay; ECG = electrocardiography; AF = atrial fibrillation; ICU = intensive care unit; IHD = ischemic heart disease
Data management and wearables in older adults: A systematic review.

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Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.
Data management and wearables in older adults: A systematic review.

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