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Collecting health-related research data using consumer-based wireless smart scales

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ABSTRACT

Background: Serious public-health concerns such as overweight and obesity are in many cases caused by excess intake of food combined with decreases in physical activity. Smart scales with wireless data transfer can, together with smart watches and trackers, observe changes in the population's health. They can present us with a picture of our metabolism, body health, and disease risks. Combining body composition data with physical activity measurements from devices such as smart watches could contribute to building a human digital twin.
Objective: The objectives of this study were to (1) investigate the evolution of smart scales in the last decade, (2) map status and supported sensors of smart scales, (3) get an overview of how smart scales have been used in research, and (4) identify smart scales for current and future research.
Method: We searched for devices through web shops and smart scale tests/reviews, extracting data from the manufacturer's official website, user manuals when available, and data from web shops. We also searched scientific literature databases for smart scale usage in scientific papers.
Result: We identified 165 smart scales with a wireless connection from 72 different manufacturers, released between 2009 and end of 2021. Of these devices, 49 (28%) had been discontinued by end of 2021. We found that the use of major variables such as fat and muscle mass have been as good as constant over the years, and that minor variables such as visceral fat and protein mass have increased since 2015. The main contribution is a representative overview of consumer grade smart scales between 2009 and 2021.
Conclusion: The last six years have seen a distinct increase of these devices in the marketplace, measuring body composition with bone mass, muscle mass, fat mass, and water mass, in addition to weight. Still, the number of research projects featuring connected smart scales are few. One reason could be the lack of professionally accurate measurements, though trend analysis might be a more feasible usage scenario.

1. Introduction

Overweight and obesity are serious public-health concerns, which potentially can result in severe illnesses such as diabetes, cancers, and cardiovascular diseases [1,2,3]. There is an escalating global epidemic of overweight and obesity, and a substantial proportion of overweight and obesity cases are likely caused by excess intake of food combined with a trend of decreases in physical activity. Especially in the light of the recent COVID-19 pandemic, obesity has been shown to put individuals in a particularly vulnerable situation [4]. The World Health Organization (WHO) has recently updated its guidelines for physical activity and sedentary behaviour [5], in which WHO outlines recommended activity for children, adolescents and adults. Globally, 25% of adults do not meet the recommended levels of physical activity [6].

Smart personal health devices can be used to monitor changes to population health because these devices enable collecting continuous lifestyle data, potentially over a longer period compared to traditional assessment methods. Smart watches and trackers will register biometric data such as activity intensity, steps, and heart rate, while smart body composition scales can be used for measurements such as the body's

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water weight, muscle mass, bone mass, and visceral fat [7 8] by using bio-electrical impedance analysis (BIA) [9]. They may present us with a picture of our metabolism, skeletal health, and disease risks. Combining data from smart wearables and smart scales can provide a more complete picture of changes in the population's health. This may reveal trends and shifts in population habits and create a body of knowledge to assist regulating health policies and improve prevention and treatment procedures.

The goal of this study is to evaluate connected smart bodyweight scales for the consumer market, i.e., devices that can measure body-mass index (BMI), weight, and body composition. We will investigate the evolution of smart scales in the last decade, as well as mapping status and supported sensors of smart scales. In addition, we aim to identify brands that are used in research projects and consider which scales would be relevant for future research in terms of data availability, sensor quality, and measurements.

2. Materials and methods

We searched for the manufacturer's self-reported data for technical data on the smart scales. To find relevant smart scales, several avenues were explored:

1. Using Internet search to find smart scale reviews, and then using these to find smart scale manufacturers [10–13].
2. Amazon bestseller lists to utilise the top 50 smart scales. For balance, bestseller lists for USA, UK, Germany, India, and Japan were used, i.e., amazon.com, amazon.co.uk, amazon.de, amazon.in, and amazon.jp, respectively.
3. Reviews from Henriksen et al. [14,15] about using fitness trackers and smart watches for measuring physical activity as a starting point, since many manufacturers of wrist-worn devices also make smart scales.
4. Smart scales supported by the Android-only openScale app [16], as used by the Quantified Self community [17].
5. Recommendations from department colleagues.

The process further was to find each manufacturer's website, to find the information on the individual smart scales, and then complement the metadata from the Federal Communications Commission (FCC) database [18], smart scale reviews, and web shops.

2.1. Inclusion criteria

Only data for smart scales with connectivity were retained since connectivity would facilitate self- recording. Only consumer market smart scales were listed, since the professional smart scales would be unavailable to, or too expensive for, the consumer market. If they were not targeted towards the consumer market, they were not included. In addition, some of the scales were included but excluded for parts of the analysis if the release year could not be identified.

2.2. Data collection

A total of 58 different variables were collected for each included weight scale, and Table 1 shows the most relevant meta-data columns outside weight.

Though not an exhaustive device search, the selected scales serve as a representative selection of current smart scales. Data collection was done in 2021 between August 2nd and December 31st and contains information on most smart scales available in this period.

Several manufacturers would not disclose all scale details on their website. We therefore had to collect additional meta-data from reviewers and/or web shops. Using the Federal Communications Commission (FCC) [19] database, some of the smart scales could also be found, with user manuals, reports, tests, and specifications.

Table 1
Relevant variables collected for smart scales.

Variable	Description
Body fat	The total amount of body fat (aka. fat mass or fat percent)
Visceral fat	Fat surrounding the vital organs in the abdominal area
Subcutaneous fat	Fat tissue peripherally located throughout the body
Lean mass	Total body weight minus all body fat
Muscle mass	Muscle mass in the body
Protein	Fat-free mass minus water, minerals, and bone mass
Skeletal muscle	Muscle mass responsible for moving the body
Body water	The amount of body weight that is water
Bone mass	The amount of bone mineral content in the body

2.3. Smart scales in research

A search phrase was set up for searching ACM Digital Library [20], IEEE Xplore [21], Ovid/MEDLINE [22], PubMed [23], and Web of Science [24] for smart scales. The following criteria were used:

1. Must be a bodyweight type scale, used to weigh human adults.
2. Articles should state the model, or the brand of the smart scales used.
3. Must be available at the time of research, consumer-based smart scales, that anyone can buy in a shop. In other words, they must not be professional-grade, or only available to general practitioners, researchers, etc.
4. Must be able to send data to other devices or the internet through either Bluetooth, Wi-Fi or cellular. If studies do not describe communication with other devices or the internet, a non-connected bathroom scale is assumed, and article is excluded.

The search phrase used was *("bathroom scale" OR "weight scale" OR "e-scales" OR "smart scale" OR "smart scales") AND ("body analysis" OR "body composition" OR "body weight" OR "body monitor" OR BMI OR "body mass index") AND ("bluetooth" OR "wi-fi" OR wifi OR connected OR wireless)*, with an exception for IEEE Xplore where a simpler version of the search was used. The query has three parts, finding the correct type of scale, finding the correct type of functionality, and finding connected smart scales.

3. Results

3.1. Relevant smart scales

The smart scale search procedure is presented with a flow-chart in Fig. 1. We collected data for in total 181 smart scales from 72 manufacturers using the official manufacturer's web sites, FCC database, web shops or device reviews.

We removed 16 scales because of lack of specifications, partial specification, lack of reliable information sources, or for being professional grade scales, i.e., not consumer based. The remaining 165 devices were included in the study. For 28 devices release year was not available.

We also found that 28% of the remaining 165 devices were confirmed to be discontinued (n = 47). This number could be higher, though, given the lack of specific information from brand web sites.

3.1.1. Smart scale models by year

There has been an increasing trend of wireless smart scales since the first scale found from 2009. Year 2020 shows a peak in the set of scales we found, with 28 new scales released, while 2021 is lower with 14 new scales.

Fig. 2 shows the total number of smart scale models found each year. It also shows unique manufacturers by year, i.e., counting one model per manufacturer, and new manufacturers, i.e., manufacturers that were not available the previous year.

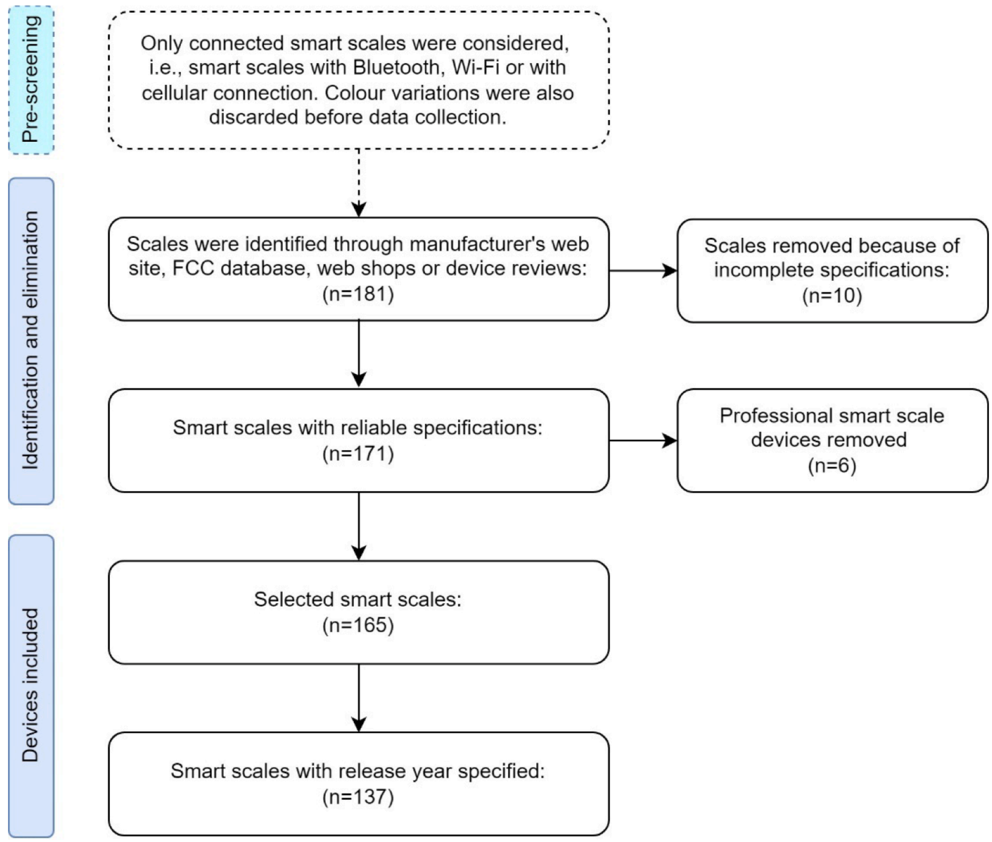

Fig. 1. A flow chart of the data collection process.

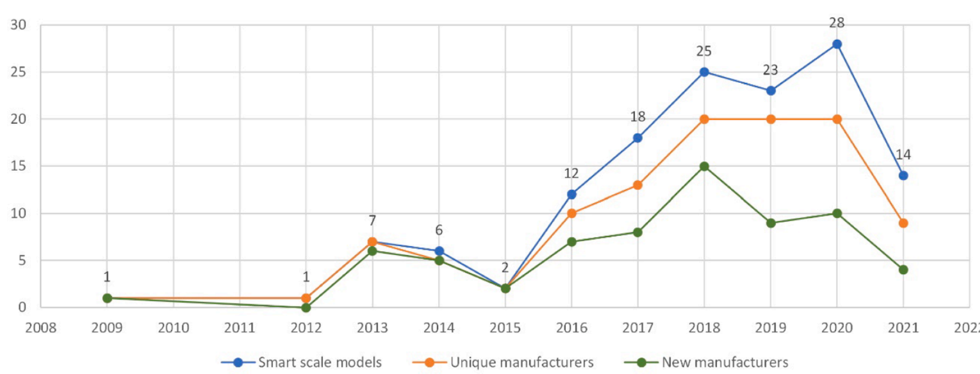

Fig. 2. Smart scale models and manufacturers found, by release year (n = 137).

3.2. Technology

All smart scales use weighing sensors, but in addition, BIA is used for measuring body composition. Of the 165 selected scales, 93% had implemented BIA technology, none had a cellular connection, 84% had Bluetooth connectivity only, some had both Bluetooth and Wi-Fi connectivity (11%), and the remaining 5% were Wi-Fi only.

Two of the smart scales (*InBody H20N* and *H20B* [25]) also use a hand-held sensor "bar" while measuring body composition, producing a more detailed measurement, which also give body composition measurements for limbs vs. torso, e.g., how much fat in arms and legs vs. fat in torso. Thirty-two smart scales had Indium tin oxide (ITO) surfaces, to increase measurement accuracy [26].

3.3. Relevant variables

Major variables for bio-electrical impedance analysis are fat percent, muscle mass, body water, and bone mass. Fig. 4 shows that smart scale variables for lean mass, skeletal muscle, protein mass, visceral fat and subcutaneous fat have increased since 2015, while variables for BMI, body fat, body water, muscle mass and bone mass have been steady around 80–90% in smart scales released.

3.4. Usage in research

A total of 165 research studies were found, where all research databases searched contributed items to the final list of approved articles. After removing duplicates and irrelevant studies, we were left with a total of 27 articles that met the inclusion criteria, see Fig. 5.

The included studies can be divided into two groups, 1) data

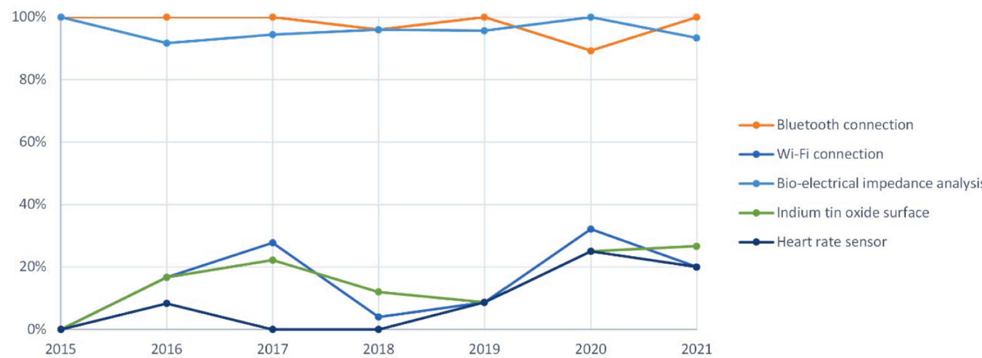

Fig. 3. Smart scale technology trends for the years 2015–2021.

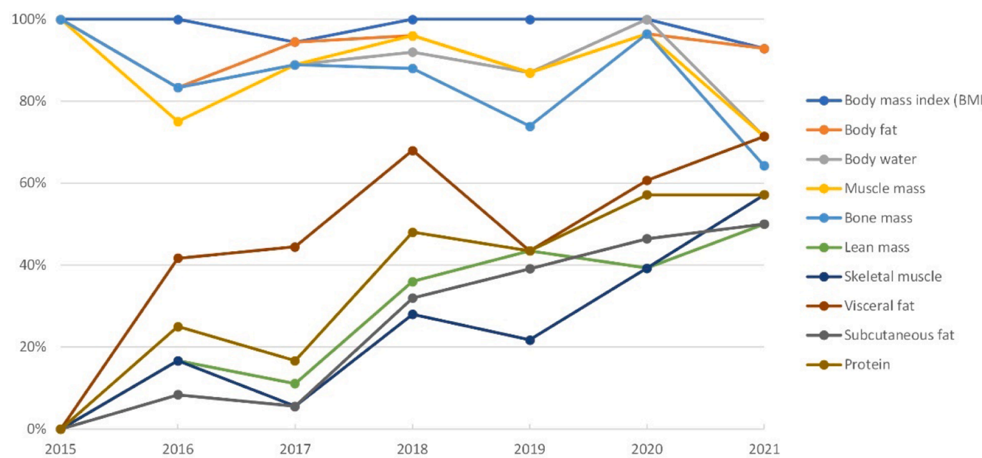

Fig. 4. Smart scale variable trends for the years 2015–2021.

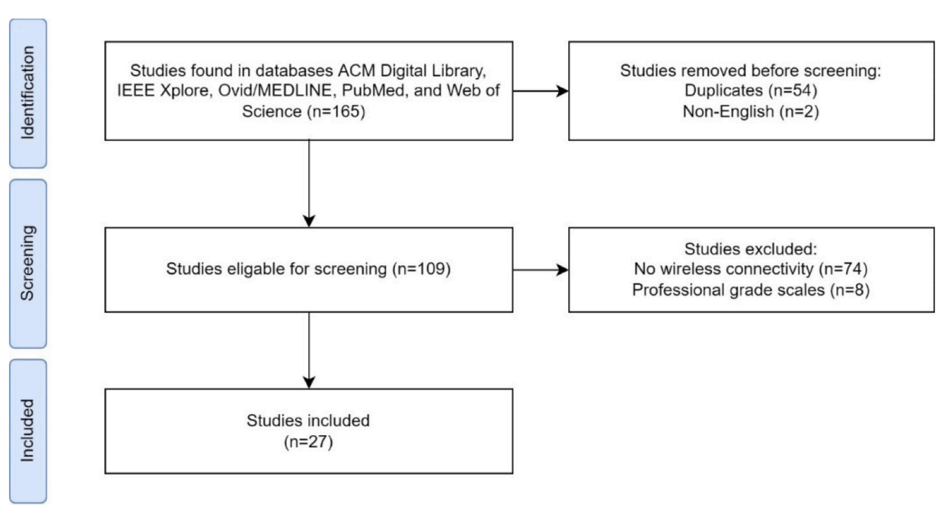

Fig. 5. PRISMA diagram for smart scale studies.

collection studies (n = 20), and 2) validation and analysis studies (n = 7). One study referred to three smart scales, so the total number of smart scale usage found within articles is n = 29.

Withings smart scales were used in 13 studies [27–39], and Fitbit scales were used in seven studies [29], [40–45]. Brands found in other studies were A&D Medical [46,47], Philips [48], Renpho [49], Shenzen Unique [50], Xioami [51], and Yunmai [52]. One study compared three smart scales, from Téfal, Terraillon, and Withings with DEXA scan [27]. One study did not state a scale brand, and referred to the scale as a "networked weight scale" [53].

3.4.1. *Connectivity*

Of the 29 brands/models used in research studies, 9 were Bluetooth only, 6 were Wi-Fi only, and 14 had both Bluetooth and Wi-Fi. This also means that 23 of 29 (79%) scales had Bluetooth, and 20 out of 29 (69%) scales had Wi-Fi. Cellular connection was consistently found to be on the professional scales only, and consequently not included in the list of final studies.

4. Discussion

4.1. Smart scale trends

The earliest wireless smart scale found in this search was from 2009, the next one was in 2012, see Fig. 2. Both were Withings scales. This may explain why Withings scales are the most prevalent in research studies. The apparent lack of smart scales between 2009 and 2015 makes it difficult to find definitive trends for this period, which could contain more smart scales from which information is no longer available. Conversely, devices may not have been wireless until later. A larger number of scales were found from 2016 so these form the basis of Fig. 3 and Fig. 4.

From 2013, and especially from 2016, the number of brands in the smart scale market seem to increase. In 2020, a there was a peak in the set of scales we found, while 2021 was notably lower. One can only speculate if the COVID-19 pandemic influenced the drop in number of units. In addition, we cannot rule out that some smart scales did not make it into our result list.

There still are some connected scales that do not have BIA. In our list only 12 smart scales (7.3%) lacked this technology. Most notable is maybe the newest Fitbit smart scale from 2019, Fitbit Aria Air [54]. The previous two Fitbit smart scales (Fitbit Aria, Fitbit Aria 2) both included body composition measurements, while the more recent Fitbit Aria Air did not. This development may potentially come from users not wanting or understanding body composition, or because this newer smart scale may give better return of investment for the company. It remains to be seen if Fitbit in removing this option could signify a trend in future smart scale development. The challenge of using smart scale-derived body composition was highlighted in a recent report suggesting that smart scales should not be used routinely in patient care due to large measurement errors [27].

Indium tin oxide surface covering was found on 19.3 % of the selected smart scales. Looking at Fig. 3 we can see that ITO has been in use for many years and has had a minor increase in use since 2019. One concern with ITO is the cost of Indium and the need for higher temperature in the production process [26], which may be a reason ITO is not more prevalent.

Weight, fat percent, muscle mass, body water, and bone mass have all largely been present in the connected smart scales. These could be viewed as the “main” measurements. In addition, we have seen an increasing trend for measurements like lean mass, skeletal muscle, protein mass, visceral fat, and subcutaneous fat. There might be several reasons for this, such as better BIA accuracy being able to produce more detailed parameters or increased public interest for additional body composition information with high relevance for health status, such as visceral fat [55]. Another reason may be that manufacturers add features to compete with other brands, making their own scales more attractive for the consumer market.

4.2. Smart scale usage

Since scales are stationary and placed on the floor, the user needs to actively move to the scale, then activate it and wait for the measurement to finish. This goes for weight measurement, but if the user in addition is measuring body composition they need to remain still until the smart scale have indicated that the measurement is completed. This could result in measurement errors or missing data if the user aborts the weighing/measuring.

Smart scale connectivity type is another hurdle for uploading measurements. In case of a Bluetooth connection, normally a mobile phone needs to be connected, usually with the mobile application active. Some applications require the user to start the weighing from the mobile phone. All this makes it more difficult for the user and might affect their motivation to complete the measurement. In the case of Wi-Fi connection, the user must set up the Wi-Fi scale with network connection through Service Set Identifier (SSID) and password, to be able to send measurements to the manufacturer’s cloud. This is still a hurdle, but when it is done, the user only needs to stand still while measurements are taken.

By far the least intrusive measurement setup is using a cellular connection. This uses mobile data connection directly to send measurements to the manufacturer’s cloud. The user only has to place the scale physically so that a connection to the mobile network is obtained. This suggests a reason for the more professional smart scales to use this type of connection. The downside of this is that it is subscription-based and adds expenses.

4.3. Consumer-based vs professional devices

Consumer-based smart scales differ from equipment used by health professionals, which may measure single parameters only but with a much higher degree of accuracy [27]. The reliability of BIA as a technology has been compared to more advanced body composition methods, and has been found interchangeable on a population level [56]. Because some smart scale measurements may not be accurate to a professional quality, the best way of using these is for the user to follow changes in measurements as a trend, and not as an accurate measurement of true body tissue content.

4.4. Manufacturers’ claimed measurements

Smart scale manufacturers rely on capturing the public’s interest to sell their scales. This implies promoting ease of use, good design, accuracy, and reliability, but also measurements that potential users find useful or interesting. However, there are limits to the accuracy of bioelectrical impedance measurements [27,57,58]. Low priced smart scales usually mean limitations to accuracy, reliability, and precision, especially in consumer-based smart scales. This is because manufacturers are not transparent in how they measure or calculate the different variables, so results may deviate from the “true” value of a body tissue. How much they deviate is not known since algorithms and measurement methods are not disclosed by the manufacturers.

Measurements like subcutaneous and visceral fat are useful to quantify the proportion of harmful fat, but less so if they are not accurate. Some of the attributes the manufacturers claim to measure are less plausible, especially because they do not declare their measurement techniques. One such measurement is “protein” or “protein mass.” This is based on a calculation from lean mass minus water, minus minerals, and is rarely, if ever, used in medical research the same way protein are described by manufacturers. Manufacturers describe muscle mass, skeletal muscle, and protein as three different measurements, although these are highly related to each other, and it is unlikely that they can be properly separated given the proposed measurement techniques. Skeletal muscle is normally included in the term muscle mass, and all muscle mass contains protein, though protein is also found throughout the body. One way to interpret manufacturers’ version of the term protein is “a number that can be easier for the user to keep tabs on when following changes to the body based on nutrition intake and physical activity”.

4.5. Implication for usage in research studies

What may be considered when using connected smart scales in studies is device availability, data obtainability, ease of use, and price. When gathering data from a population using a smart scale, ease of use is paramount. If weighing becomes bothersome, study participants might stop using the scale, thereby halting data measurement for the study. When a smart scale becomes “transparent,” in that the only thing a user needs to do is step on it, wait, and then step off, it will be easier to use. This can be achieved by using scales with Wi-Fi or cellular connection. The former needs Wi-Fi login, which could be more technical. In contrast, the latter needs a cellular subscription, which is more expensive.

Two angles on smart scale studies are gathering data from people that already have smart scales at home or supplying a population with smart scales to use. The first may skew the study population because of selection bias, the second is expensive but may give data from a more heterogenous population. Also, studies that want the measured data for subsequent processing should select smart scales from a manufacturer that has an API where stored health data could be accessed.

5. Strengths and limitations

There are several limitations to this study. The manufacturers differed as to how much of the device specification detail they would disclose, which means that there might be inaccuracies in the details for some of the scales.

Metadata collection was done manually by one researcher, which might introduce sampling bias or information bias in that some of the information could be inaccurately collected or classified. It also limits how much data could be collected due to time constraints. Collecting data manually may be prone to human errors, though it may also be a strength, in that potential errors also may be avoided that would surface in automatic data collection, e.g., web scraping [59].

Smart scales are available in different markets, Asia, the Americas, and Europe to name a few. Not all these markets were thoroughly investigated, which also can introduce sampling bias. To try to mitigate this, the top 50 smart scales in the Amazon web shop for USA, UK, Germany, India, and Japan were examined, though large markets such as China may have devices unavailable to an international audience.

6. Conclusions

This study focused specifically on consumer-based wireless smart scales because of the possibilities for health-related data collection for a population.

Collecting data over time for an individual may provide health professionals with valuable information regarding that person's health status and may help inform prevention and treatment strategies for their current health condition. Using a manufacturing term, this could be coined as a down-scaled "human digital thread." In our context it can be described as the data continuously generated by activity trackers and smart scales.

Mair et al. [60] propose using consumer-based activity trackers as data collection devices, with the caveat that these devices have limitations. Consumer-based smart scales could also be added to the collection of data collection devices.

A combination of consumer-based activity trackers and smart scales would give a more comprehensive insight into individuals' health status. And even if individual measurements may not be precise for use in health care directly, data collection for an entire population would even out the measurement inconsistencies.

Author contributions

EJ conceptualized and designed the study, with contributions from AH. EJ collected smart scales and conducted the literature search for smart scale usage in research. EJ did the original draft preparation, with critical review by all authors. All authors read and approved the final manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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