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Emerging Applications

“It’s Not as Simple as Just Looking at One Chart”: A Qualitative Study Exploring Clinician’s Opinions on Various Visualisation Strategies to Represent Longitudinal Actigraphy Data

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Keywords

Visualisations · Actigraphy · Physical activity · Wearable technology

Abstract

Background: Data derived from wearable activity trackers may provide important clinical insights into disease progression and response to intervention, but only if clinicians can interpret it in a meaningful manner. Longitudinal activity data can be visually presented in multiple ways, but research has failed to explore how clinicians interact with and interpret these visualisations. In response, this study developed a variety of visualisations to understand whether alternative data presentation strategies can provide clinicians with meaningful insights into patient’s physical activity patterns. **Objective:** To explore clinicians’ opinions on different visualisations of actigraphy data. **Methods:** Four visualisations (stacked bar chart, clustered bar chart, linear heatmap and radial heatmap) were created using Matplotlib and Seaborn Python libraries. A focus group was conducted with 14 clinicians across 2 hospitals. Focus groups were audio-recorded, transcribed and analysed using inductive thematic analysis. **Results:** Three major themes were identified: (1) the importance of context, (2) interpreting the visualisations and (3) applying visualisations to clinical practice. Although clinicians saw the potential value in the visualisations, they expressed a need for further contextual information to gain clinical benefits from them. Allied health professionals preferred more granular, temporal information compared to doctors. Specifically, physiotherapists favoured heatmaps, whereas the remaining members of the team favoured stacked bar charts. Overall, heatmaps were consid-

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ered more difficult to interpret. **Conclusion:** The current lack of contextual data provided by wearables hampers their use in clinical practice. Clinicians favour data presented in a familiar format and yet desire multi-faceted filtering. Future research should implement user-centred design processes to identify ways in which all clinical needs can be met, potentially using an interactive system that caters for multiple levels of granularity. Irrespective of how data is displayed, unless clinicians can apply it in a manner that best supports their role, the potential of this data cannot be fully realised.

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Introduction

Wearable technology is increasingly used in healthcare to support the management of chronic conditions [1, 2]. The use of research-grade wearables (e.g., Actigraph) to measure endpoints in clinical trials [2–4], and the rise of consumer wearable companies such as Fitbit [5], demonstrates the acceptance of this technology in the wider community. Despite their popularity, a lack of integration into clinical practice calls into question the potential value offered by these devices to patients and clinicians. It is suggested that unless wearables offer useful insights and outcomes, and not simply data, their promise will not be realised [6]. To be fully integrated into clinical environments, the data from wearables must be simple to access, use and understand [7–9]. Put simply, it must enhance the clinical decision-making capability of the clinician, or empower the patient, to be more engaged in self-management. Thus, the manner in which raw data is processed and presented is critical to the success of these devices within this context [8, 10].

Longitudinal actigraphy data can be presented in two ways: (i) summary metrics of total daily activity, steps or sleep and (ii) a more granular approach whereby within-day physical activity (PA) and sleep data is represented over time. However, a reliance on summary metrics remains, driven by the approach used by consumer wearable companies (e.g., Fitbit, Apple etc.). Clinically, this fails to provide information about the temporal nature of activity. In other words, it provides an understanding of how much people move or sleep, but not how this is dispersed within days, weeks or months. Recent research suggests that more complex methods of data processing may provide more meaningful clinical insights [11], while users may value further detail than that which is currently provided by many devices [12]. More granular visual representations of data may offer the ability to quickly identify patterns and understand behaviour, therefore informing clinical decision-making and driving increased use of wearables in practice [10, 13].

There has been little research exploring the perceived value of commonly employed visual representations of the data from wearable devices [14]. A study in 2012 presented ways in which longitudinal data could be visually represented. However, graphs were limited to summary level information and the intended users' perceptions were not investigated [7]. To best support the implementation of wearables in practice, it is important to trial advancements on those who will be using them. Clinicians possess the knowledge required to identify important patterns for decision-making [15]. Thus, it is critical to understand whether they perceive any outputs derived from these devices to be clinically useful, whether they can accurately interpret visualisations independently, and what insights they gain from them. Therefore, this study developed a variety of visualisations of longitudinal actigraphy data, both “state of the art” as commonly seen in current commercial devices, and more granular, temporal representations of the same data. The aim of this study was to explore clinicians' opinions of these data visualisations to determine their perceived clinical utility.

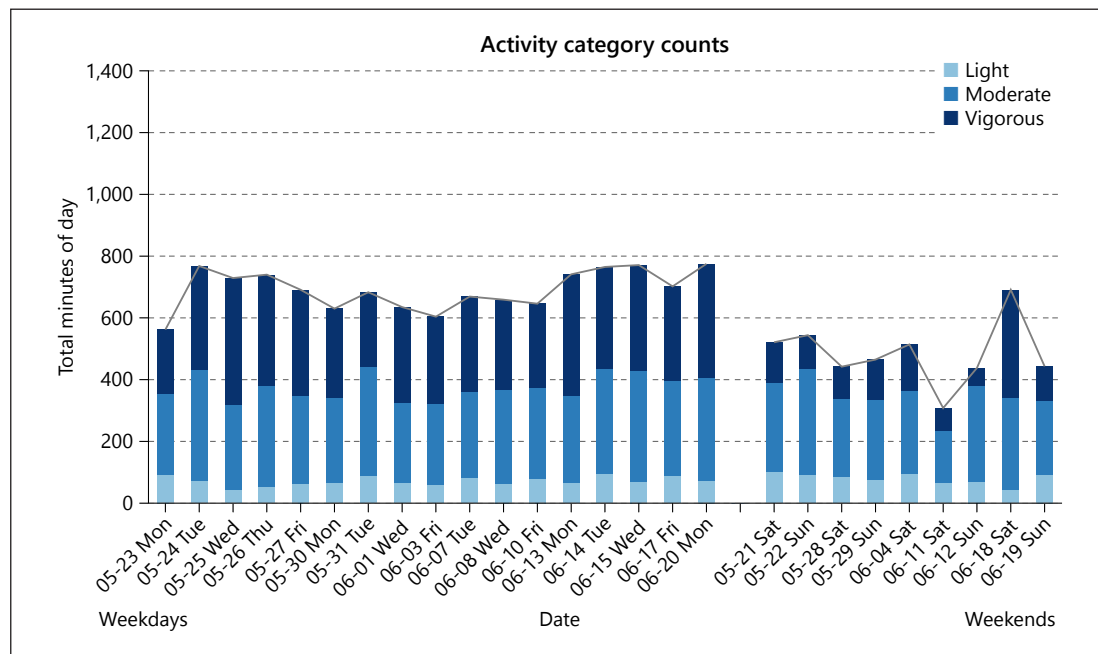


Fig. 1. Example of a stacked bar chart.

Material and Methods

Ethical approval for this cross-sectional, qualitative study was granted by the Human Ethics Board of the local research institution.

Data Processing and Visualisation

The visualisations were created using activity count data (a threshold-based proxy of movement) previously collected from arthritis patients using an Actigraph GT9X Link (Actigraph LLC), as reported elsewhere [11, 16, 17]. Arthritis patients wore the Actigraph during their usual activities for a period of 28 days. Raw data were pre-processed and 60-s epoch activity counts generated. Study days were converted to *data analysis days* (DADs). A DAD starts at 18:00.000 and ends at 17:59:000 the following day. The absolute values of activity count for each epoch were converted into 4 PA categories: inactive, light, moderate and vigorous [18].

Three participants were selected to provide a comparison for how different activity and pain profiles may present across arthritis populations. Four visualisations were created for each patient; a stacked bar chart (Fig. 1), a cluster bar chart (Fig. 2), a linear heatmap (Fig. 3) and a radial heatmap (Fig. 4). The 4 graphs present identical Actigraph activity count data for each patient across a 28-day period. The visualisations were created in Python using the *Matplotlib*, *HoloView* and *Seaborn* libraries. DADs were labelled with “date day” format where the date was the date in the DAD which covers the morning time. In all but the radial heatmap (Fig. 4), weekdays and weekends were separated to facilitate interpretation of daily activity patterns. In the stacked and cluster bar charts (Fig. 1, 2), total activity for each day was shown, separated into the different PA categories. This represents the current “state of the art” provided by consumer devices such as Fitbit [19] and Apple Watch [20]. A monochromatic ordinal colour scheme from ColorBrewer [21] was used to indicate the different categories. The linear and radial heatmaps portrayed continuous activity count data, facilitating

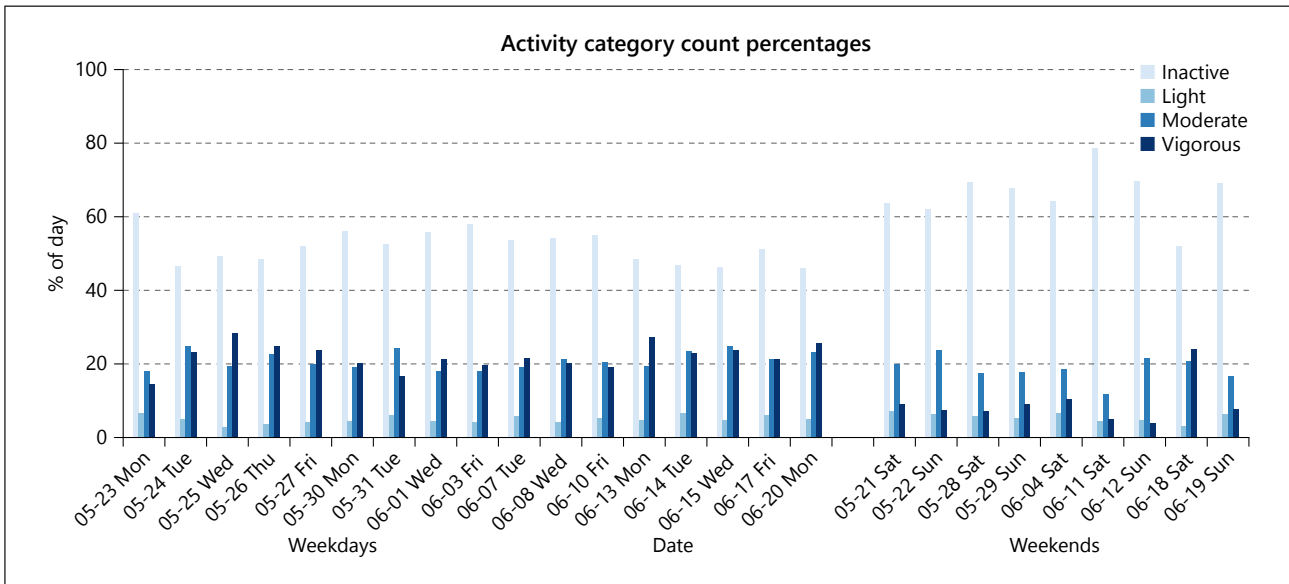


Fig. 2. Example of a clustered bar chart.

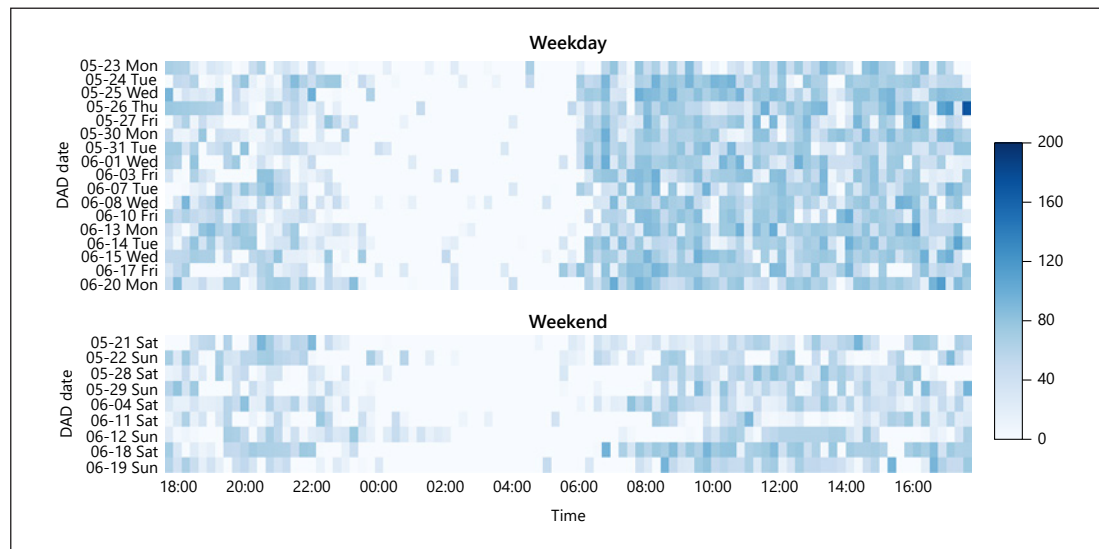


Fig. 3. Example of a linear heatmap.

comparison of the temporal patterns of PA within and between days. This approach is not commonly used by consumer devices. Each cell represented the total activity count for a 15-min epoch. A monochromatic sequential colour scheme [21], was used to indicate the activity level in that epoch. To prevent a small number of very high values saturating the scale, colours were mapped to the square root of the activity counts.

Participants

Fourteen clinicians were recruited using purposive convenience sampling across 2 hospitals in Ireland (Table 1). The lead clinician of the medical team in each hospital was contacted through email. All interested clinicians were invited to take part in a focus group within their hospital at a suitable time and provided written informed consent to participate.

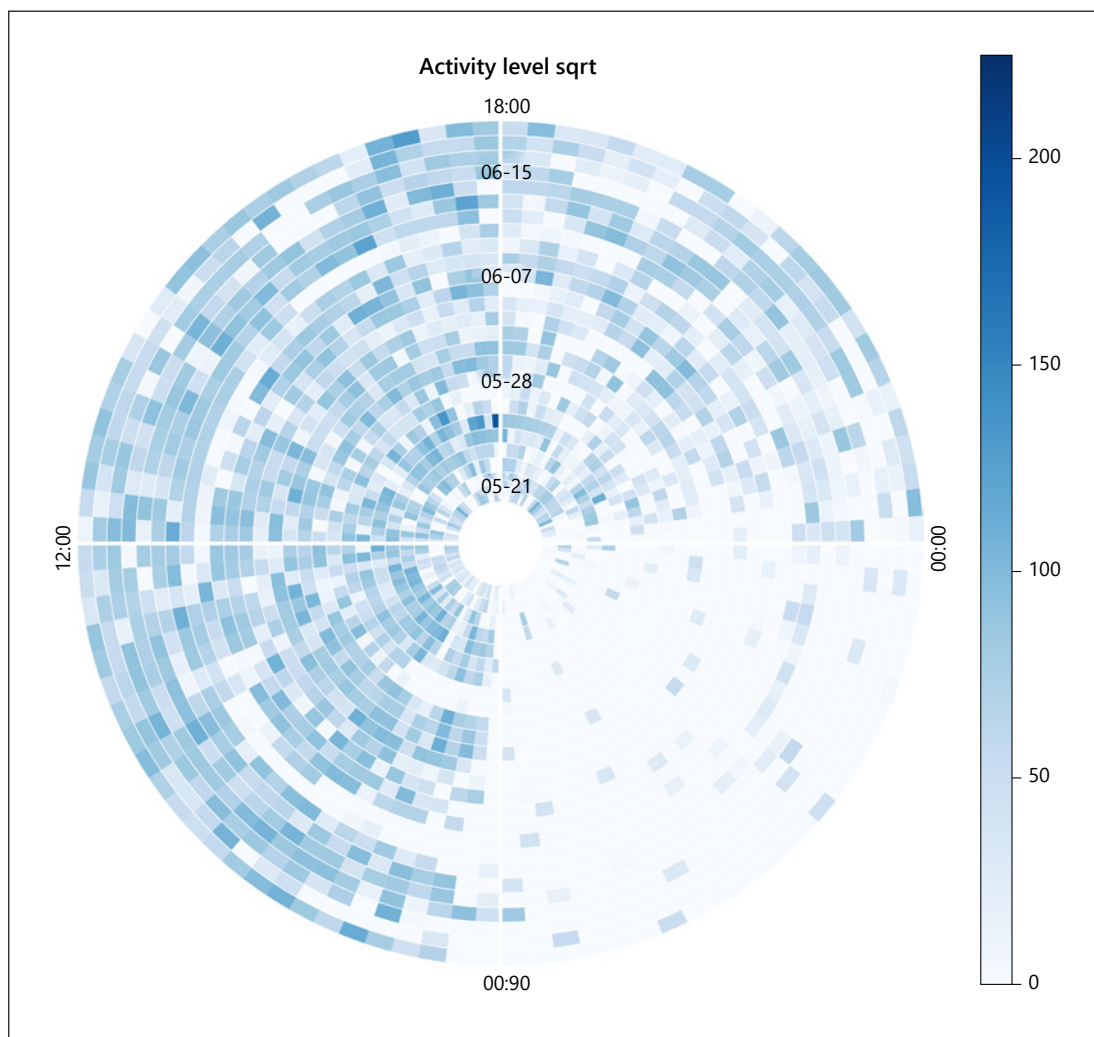


Fig. 4. Example of radial heatmap.

Table 1. Participant information

<i>Sex</i>	
Male	5 (35.7%)
Female	9 (64.3%)
<i>Role in the clinical team</i>	
Doctor	
Consultant rheumatologist	3 (21.4%)
Registrar (rheumatology)	3 (21.4%)
Physiotherapist	
Clinical specialist	2 (14.3%)
Senior physiotherapist	2 (14.3%)
Occupational therapist	
Senior occupational therapist	2 (14.3%)
Nurse	
Rheumatology	2 (14.3%)
<i>Years of clinical experience</i>	
>10 years	14 (100%)

Protocol

Focus groups were facilitated by 2 post-doctoral researchers (1 female [A.K.] and 1 male [W.J.]), both of whom were physiotherapists specialising in digital health. Alison Keogh previously published research in qualitative methods and analysis and William Johnston has extensive experience with data derived from wearable devices. Each focus group took 60 min to complete and was audio-recorded and transcribed verbatim by Alison Keogh. No follow-up interviews or clarifications took place.

The focus group explored clinician's experiences regarding patient-generated activity data (online suppl. File 1, see www.karger.com/doi/10.1159/000512044). Clinicians were provided with the 4 visualisations from each of the arthritis patients, along with a brief clinical history detailing the sex, age, condition, average pain and stiffness and the SF-36 physical and mental domain scores, for each patient profile. Clinicians were asked for their insights into each visualisation independently, including whether they were useful, what clinical understanding could be derived from them, and what further information, if any, they required to support their clinical judgement. As the focus group progressed, comparisons between the visualisations were encouraged.

Data Analysis

An inductive, thematic analysis was undertaken using a realist approach whereby the researcher assumed that the opinions of the participants reflected their true perceptions and should be taken as real [22]. Transcripts were analysed by Alison Keogh and William Johnston following the suggested protocol of Braun and Clarke [22]. Both researchers familiarised themselves with the data, generated a list of initial codes relevant to the research question, and refined these codes by grouping them into potential themes. This list was continually reviewed until agreement was reached.

Results

Three major themes were identified: (1) the importance of context, (2) interpreting the visualisations and, (3) applying visualisations to clinical practice. Supporting quotations are provided in Table 2.

The Importance of Context

None of the clinicians routinely used this type of data with patients. Clinicians extensively reported that, irrespective of the visualisation used, the data alone were not enough to provide clear clinical insights without also understanding the context in which it took place. Context was multi-faceted including wanting to know participants daily levels of pain/stiffness, the type of activity they were engaged in, their employment status, and so on. Without this information, the relevance of the data was questioned, although it was acknowledged that it could be used as an additional tool to drive assessments, evaluate treatment effectiveness and act as a benchmark for patient progress.

- *"It's hard to read into that because we don't know how they've done those steps or what pace they've done them or what intensity, whether they're done them all together or whether it's just pottering about as the day went on."* [Physiotherapist 1, female]
- *"This would be another great thing to have in addition to you know, asking the patient if they have swollen joints, tender joints, eh asking them are they more active or not, early morning stiffness, but this might actually give us a more objective view of if they're being correct."* [Consultant 2, male]

Table 2. Supporting quotations linked to the three major data themes

Theme	Quotation
The importance of context	<i>"I think you need more than just numbers of how many steps they did each day or an average per week, you need background, more subjective information about how their symptoms were."</i> [Physiotherapist 2, male]
	<i>"I guess what I'm saying is this tells you whether this person is moving, but it's not normalised against you know a group of people stratified to his age or his occupation."</i> [Consultant 1, male]
	<i>"They're doing a good bit of vigorous activity during the week but it's hard to know is that them going to the gym, or is that just going up stairs. It would just be nice to have context."</i> [Registrar 1, female]
	<i>"You would just need to look at the whole picture and it's going to help you form your treatment point of view as well, how you're going to get them to do what they're going to do."</i> [Physiotherapist 3, male]
	<i>"I think it would be really helpful, like for something to use practically, to really see how it's going to fit into your clinical practice, because I have these concerns as I've said before, that it doesn't include patients perceptions of their efforts. In particular some of our debilitating patients, that you know are probably coming up as low activity for much of the day in these graphs but to them something like making their dinner or going for a short walk is a major achievement. But you probably wouldn't pick up those subtleties in this."</i> [Physiotherapist 1, female]
	<i>"We measure disease activity in a snapshot, so maybe baseline, six weeks, three months type of thing."</i> [Consultant 1, male]
Interpreting the visualisations	<i>"But I think if inactivity was broken up into sleep and inactive time, because we've got cohorts, and I've flipped through all participants and like their sleep patterns vary, or their inactivity varies, but is that because part of it is pain, you know they're inactive before 8 because they've stiffness and that's how long it takes them to get going before they can do activity."</i> [Nurse 1, female, referring to Figure 2]
	<i>"Yeah like that graph, you can straight away start discussing and asking questions, it's pretty instant. If you've seen this type of graph and it was something that we were administering and we knew what the graph looked like it would be really easy to straight away start discussing their data"</i> [Physiotherapist 2, male, referring to Figure 2]
	<i>"It is a bit misleading though when you don't have the sleep in there because you know that's all included in the inactive time. So if you were able to look at sleep as an extra thing and then inactive time."</i> [Physiotherapist 4, female, referring to Figure 2]
	<i>"I think it would be good to have some examples as to what that particular device would rate as light, moderate and vigorous. Because we don't really have a reference scale for that."</i> [Physiotherapist 1, female, referring to Figure 2]
	<i>"What's really interesting in this graph that you don't get from the others is that when you look at the gradation of the blue, obviously all the other, how do they phrase it, high activity, vigorous activity, it looked like that certain patients were doing quite a bit of vigorous activity, but when you look at it in this graph, between three people there's only maybe two squares that are very high activity levels so it does give you a lot more information in terms of the intensity I think."</i> [Physiotherapist 1, female, referring to Figure 3]
	<i>"The activity is much easier to see actually, just straight off it jumps out at you really. You can deduce it from the other that they're probably working during the week and then sitting round at home at weekends, but you can see that inactivity is highlighted here which is good."</i> [Consultant 1, male, referring to Figure 2]
	<i>"I think my initial thought was that it was a bit confusing and I'm not sure, but I suppose now I could see where I could start to talk through certain things with patients with this graph but I think visually, initially it takes a bit more time to get your head around it."</i> [Physiotherapist 2, male, referring to Figure 3]
	<i>"I'd actually probably prefer if it was just Monday to Sunday."</i>
	<i>"I'd agree."</i>
	<i>"You might see trends there visually better."</i>
<i>"I think it depends as well on the population or whether they're working or not. You know, if they're working it might be useful to see like to have this split into weekdays and weekends but say, for example, in my study over 80% of people were not working so in that case I don't think you would need to necessarily separate the data."</i> [Physiotherapists 3, male, 1, female and 4, female, referring to weekends]	
<i>"And I think the time of day is really useful to have that and to be able to see it in the 15 minute intervals because it allows you see whether they are doing prolonged periods of high activity or long periods of low activity and what time of day it's happening."</i> [Physiotherapist 1, female, referring to Figure 3]	

Table 2 (continued)

Theme	Quotation
Interpreting the visualisations	<i>"It would be interesting I think to compare those to patient's perceptions as to how much they felt they were exercising to a moderate or a vigorous extent because that would be very different."</i> [Physiotherapist 1, female]
	<i>"Definitely a number is better than this because it's something that you can just glance at and you know it's easy to put into a medical record and track, you know, it's just a number."</i> [Consultant 1, male]
	<i>"It's too subjective, the colours are so merged together and so similar in colour, it's a variation of the same colour. Even if they were different colours it might be more visually clear but to me that's just like a mosaic tile that's a mish-mash of data."</i> [Occupational therapist 2, female, referring to Figure 3]
	<i>"I suppose the one thing I think about the last two graphs, even though overall you do get more information, is that in giving more information it's almost harder to interpret their activity if you know what I mean. I think when its divided into three categories, whether that's accurate or not, it creates a very clear differential, whereas when you look at these graphs, and all the different shades of blue with quite subtle changes between them, it makes that very hard to interpret well what's the difference really."</i> [Physiotherapist 1, female]
Applying visualisations to clinical practice	<i>"I didn't find it great to be honest. I then had to I suppose, I mean it was useful in that you could pull it out as an Excel file and then take that data that I needed. Ehm, and then I analysed it in Excel using the functions of Excel. But it, it just, I think the numbers really only tell so much. A patient wouldn't really be able to take anything from that."</i> [Physiotherapist 4, female]
	<i>"The patients that jump put to me are maybe patients that we don't see all that much. Like your metabolic type syndrome patients, your diabetic patients, your cardiovascular patients who maybe don't have pain limitations to the amount of exercise that they do, and where increasing their physical activity is a huge goal for their general health."</i> [Physiotherapist 1, female]
	<i>"And I suppose you approach it as it's just another tool within your box as such in that there'll be some patients who this will be more useful for than others, and there's some patients who will take more from it than others and there's some that maybe, like those low functioning patients may not do very well initially but you know, six months down the line perhaps they'll see that activity change and actually you know they'll get that feedback from that. Because sometimes it's very difficult for them to perceive that they've changed because it's subtle and gradual every time and if you could show them a map that they were getting very little of the darker blues and then over time if they get an awful lot more, then it would still be useful."</i> [Physiotherapist 1, female]
	<i>"It could certainly be an adjunct you know and in particular for sensitivity to change and in particular for younger individuals, maybe people that require motivation, you know but also to measure the response to the effect of treatment."</i> [Consultant 1, male]
	<i>"If it's discordant, if the summary scores are discordant you could actually go back and look at the graph and see why its discordant, is there a pattern in the graph and to actually, the summary scores would be good to have. For most people that would be fine, and then for a couple of patients you could be like that's more discordant than I thought it would be or there's something different there, then you can go back and look at actually each day in this kind of bar chart or whatever, and then you'd see where the pattern is."</i> [Consultant 2, male]
	<i>"Because it's not something that has been a part of maybe our way of working then I suppose I wouldn't routinely ask people if they have a Fitbit for example or their activity levels from that perspective."</i> [Physiotherapist 1, female]
	<i>"I think you'd probably, after a while, would get an idea when you're doing your subjective, objective, ok this person would be quite good to use graphs on possibly. And you'd kind of go from there rather than right we're going to use graphs, here's a Fitbit. You'd probably pick and choose your patient."</i> [Physiotherapist 3, male]
<i>"You know the way on a photograph on a phone you can zoom out and zoom in? If there was any way that you could manipulate the chart, any of the charts, that you could extrapolate more data if you zoom into something or pull it out so that the data is there if you want it but if the first picture you're seeing of a regular size image is grand, but then to be able to pull it out or pull it in would be wonderful to merge the two, so that that's there if you want it, on a particular time block but if you don't need it, the bigger, regular picture is fine."</i> [Occupational therapist 2, female]	

Linked to this, was a desire to understand how patients compared to other people. There were mixed opinions regarding whether symptoms of pain or stiffness would be expected to correlate with PA patterns; therefore, there was a need to understand how patients were progressing both individually and compared to the general population.

- *“This isn’t controlled for anything, this is just a man over a 4-week period and we don’t know much about him. But if we knew what he had been like 1 day and maybe after an intervention that’s where it becomes useful at an individual level but at a population level this doesn’t mean anything to me unless I know what the other people doing his work at his age in life, what they’re doing.”* [Consultant 1, male]

Interpreting the Visualisations

There was widespread agreement about the usefulness of separating periods of sleep from activity data (e.g., within Fig. 3, 4). Physiotherapists valued the ability to view a full day temporally, which was somewhat supported by occupational therapists but not by doctors, who felt this level of detail was not important.

- *“I suppose the timing of when they’re active isn’t of interest automatically but it would be more in the context of how they were feeling. You know say we put them on a new tablet and we could see that their evening exercise had increased because of the medication you know to be relevant to us it would need to be in the context of their treatment or what they are doing.”* [Registrar 1, female]

Figures 1 and 2 were considered easy to interpret as clinicians could quickly identify the categories of activity a patient was spending time in, compared to the gradient approach provided in Figures 3 and 4. Many clinicians required some form of support from the researchers to fully interpret Figures 3 and 4. Indeed, 1 clinician responded viscerally to Figure 3, remarking that *“This makes me feel sick.”* It was also noted that Figure 4 was more difficult to interpret as it was not possible to separate days, while the nature of the visualisation suggested that the days on the inside of the dial were less significant than those in the outer rings.

- *“Unless you’re used to looking at these type of things actually, just in different types of molecular biology you get these different types of graphs and eh, I always have to stand back and think about it before figuring out how to interpret it.”* [Consultant 2, male, referring to Figure 3]

There was disagreement between physiotherapists and the other members of the team regarding which visualisation they would use clinically. Specifically, physiotherapists preferred the detail provided to them in Figures 3 or 4. All other clinicians favoured Figure 1, due to its simplicity. Nonetheless, it was acknowledged that Figure 1 still required amendments to enhance its utility, specifically that sleep should be separated from other activity, that summary statistics should be provided alongside the graph and that reference data should be included for comparisons.

- *“I get more from this one definitely. I just I feel I have a better understanding of their 24-h pattern.”* [Physiotherapist 3, male, referring to Figure 3]
- *“Because it’s easier on the eye. It contains the same data, I mean they all contain the same data but that’s readable whereas the others are harder to read. The second one the bars are too narrow and the active parts are almost impossible to see. And then the third and fourth ones are, they contain a lot of qualitative information which you know may be useful from an occupational context but not in a medical context.”* [Consultant 1, male, referring to all Figures]

Applying Visualisations to Clinical Practice

Currently, clinicians rely on patients to provide them with their own data through their own, personally purchased devices. Thus, a range of barriers were noted including the digital literacy of patients, a lack of availability of these devices, the cost of implementing them, an inability to merge the outputs with patient health records, and, overwhelmingly for doctors, a lack of time. In general, allied health professionals desired greater detail than doctors; thus, how visualisations are used in practice will depend on which member of the team they are presented to.

- *“Not within the boundaries of a 15-min medical consultation. It’s just not something medically that we would practically be able to engage with. It might be different you know for longer consultations, maybe OT?”* [Consultant 1, male]
- *“I think in terms of managing fatigue and pacing it would be a really good visual for a patient to say look we talked about pacing, you’re clearly highly active day on day and you’re still saying you’re fatigued. Might this be why?”* [Occupational Therapist 2, female]

Nonetheless, clinicians could see the potential value in the information provided by wearable devices. Cohorts that would benefit from this type of data were highlighted, including those with lifestyle-related conditions such as diabetes. Furthermore, it was suggested that an interactive method of selecting which data could be viewed would be beneficial (Table 2). However, for now, it was noted that this would not be suitable for all patients, and thus clinical judgement would be required to decide where and how they were implemented.

- *“I think seeing is believing for a lot of people. I think like XX was saying you might psychologically have had a few really crappy months but if it’s here and it’s there to show you well actually look at this, this says otherwise and it’s an objective viewpoint so it does really help reinforce.”* [Occupational therapist 1, female]

Discussion

This study explored clinician’s opinions on a range of visualisation strategies using actigraphy data. Clinicians provided suggestions for how visualisations could be improved. However, what also emerged was a broader picture of the structural barriers and clinical parameters that need to be considered before the use of wearables becomes widespread in clinical practice. Specifically, the current reliance on consumer devices which target the needs of the general population, limits the potential clinical insights that can be derived from their data, due to the lack of context and individualisation provided by them.

Irrespective of the visualisation, clinicians would have required further information to use them in a clinically meaningful manner. The need for patient-specific insights is not new [9, 23, 24]; however, it remains complex as what is required for one patient may not be required for all [25, 26]. In theory, wearables should offer a greater understanding of context than currently used outcome measures [5, 10, 27, 28]. In practice however, clinicians still deemed this approach as too ambiguous, as the multifaceted nature of chronic conditions requires an understanding of numerous aspects of patient’s lives [25]. Central to the need for context was a hypothesis that additional information would help determine whether relationships between health parameters exist. Establishing correlations is an important aspect of evaluating patient progress [15]; however, recent research suggests that reported pain outcomes and PA do not correlate [11]. Though clinicians were aware of this, they nonetheless felt that it would encourage them to use the actigraphy data if they could judge it for themselves.

For visualisations to be implemented, they need to meet clinical needs [10]; however, needs may differ substantially between medical team members. The perceived usefulness of

each visualisation relied on who was using it and what information they sought from it. Thus, no single visualisation can be universally better than the other, as the individual data needs of each team member will be different. The role of allied health professionals better supports discussions around lifestyle factors [23, 29] as seen by their desire for more subjective interpretations of data compared to doctors. In contrast, current healthcare structures require doctors to focus on validated endpoints to assess patients swiftly in the limited time available to them. In the absence of a readily interpretable measure linked to PA [30], the barrier of time severely limits doctors' use of longitudinal actigraphy data [15, 31].

The results of this study support those of previous research which suggest that participants favour data that is presented in a familiar format and yet desire multi-faceted filtering [15]. It has been suggested that “*in an ideal world, end-users would be able to select the data visualisations that best suit their needs*” [10], a need further endorsed by clinicians in this study. It is clear however that the current “state-of-the-art” method used by activity trackers, particularly consumer devices, of presenting PA data ungrounded in the context of the user's condition, does not meet clinical needs. As such, if this technology is to be incorporated into practice, solutions which facilitate the amalgamation of actigraphy data alongside contextual data that are relevant to the specific clinical needs of the various healthcare professionals are required. Research-grade devices such as Actigraph already have an application associated with them; therefore, developing these platforms further to incorporate self-report measures should be promoted. However, even with such development there is also a wider barrier that is worth noting, which is beyond the remit of this paper to discuss in depth: the availability of data to clinicians. Furthermore, access to this data remains difficult, thus further limiting clinician's abilities to utilise it [32]. Currently, Irish hospitals do not have the resources to provide patients with wearable devices; thus, clinicians rely on patients collecting their own data using consumer devices. Recent calls have been made to allow this data to be easily transferrable to clinicians [32–34], however, significant regulatory changes are required before this may happen.

Limitations

This exploratory study used a sample of convenience; therefore, it is unlikely that data saturation was reached, and so further research in this area is required. Furthermore, recruited clinicians had over 10 years of experience each and so may be less inclined to introduce new tools into practice. Additionally, a pragmatic decision was made to limit the visualisations to 4 to not overburden clinicians within a single focus group. However, a variety of alternatives exist. A user-centred design process is needed to determine the best way to integrate the needs of all clinicians, including the questions that they need answered, into future visualisation strategies to allow them to deliver the individualised, patient-centred care that current structures make difficult to achieve.

Conclusion

Although clinicians agree that the data derived from wearable devices may be useful, current devices fall short. Widely used devices, both consumer and medical grade, have only recently begun to enable users to either actively or passively collect contextual information regarding their PA, and for many devices this feature is still lacking. Significant improvements in both the data captured by these devices and the manner in which it can be displayed are required. Although there was no consensus among clinicians on the depth of context desired, they agreed that without it, the data did not currently support their practice. Irrespective of how data is displayed, until clinicians have a way in which they can apply it in a manner that best supports their role, the potential effectiveness of this data cannot be fully realised.

Statement of Ethics

The study protocol was approved by University College Dublin research institute's committee on human research (LS-E-20-83-Keogh-Caulfield). The participants of this study gave their written informed consent prior to participation.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

B.C. devised the study concept which was then refined with the wider team. B.M. and N.S. completed the data processing. B.M., N.S., J.F.D., and M.A. designed the visualisations. S.D., R.M., F.C., and J.F.D. were involved in the collection of the participant actigraphy data. A.K. and W.J. designed, ran and analysed the focus group meetings. All authors contributed to the final manuscript.

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