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Opening the black box of fitness tracking: understanding the mechanisms of feedback in motivating physical activity among older Singaporeans

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ABSTRACT

This paper examines how older adults interact with fitness trackers and how that interaction influences their physical activity. We carried out qualitative interviews with 22 individuals between the ages of 55 and 72 who had used fitness trackers as part of a six-week field experiment investigating the effects of feedback from fitness trackers and the social influence of their spouses. From their comments, we derived an explorative process model explaining the mechanisms and the four stages of effects arising from personalised feedback, namely, cognitive, affective, conative, and intuitive. These effects were grouped into internal and external dimensions. Three types of goal-related decisions determined whether interviewees moved from the internal responses of cognition and emotion to the external response of behaviour change. The findings from this study elucidate how real-time personalised feedback can motivate physical activity among older adults and highlight the goal-related factors that influence this effect.

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Mobile health; wearables; fitness trackers; behaviour change; personalised feedback; real-time feedback

Singapore is facing the challenge of caring for an aging population (National Population and Talent Division 2013). Making this more difficult is the fact that 70% of Singaporeans above 60 years old do not engage in regular exercise (Ministry of Health 2020). Based on a conservative estimate, the repercussions of physical inactivity cost 53.8 billion international dollars (equivalent to USD) worldwide in 2013 (Ding et al. 2016). In the past, Singapore's healthcare system was focused on acute care for diseases, but this approach is not sustainable in the face of changing demographics (Chan and Matchar 2015). Boosting older adults' physical activity levels can lead to independent and healthy aging through improved health and prevention of non-communicable diseases (Yao et al. 2019), thereby lessening the strain on public healthcare.

Health information and communication technologies (ICTs) have gained increasing prominence in motivating health behaviour. Modern technologies such as smartphones or wearable trackers can aid the management of physical activity, supporting older adults toward an active lifestyle and preventing functional decline (Helbostad et al. 2017). Despite the many behaviour change techniques built into health ICTs, there is a lack of clarity on which ones motivate physical activity and how they do so (Sullivan and Lachman 2017). This study focuses on feedback from fitness trackers and digs deeper into how it motivates physical activity among older adults.

1. Literature review

Theorisation suggests a positive correlation between the use of health ICTs and physical activity, but the empirical evidence shows that their effects may be transient or lack tangibility. A meta-analysis of 17 randomised controlled trials revealed that interventions administered through computers or mobile or wearable technologies effectively reduced sedentary behaviour, but the effects were not sustained in the long-term (Stephenson et al. 2017). Whereas wearables and smartphone applications may lead to higher levels of self-reported physical activity (Edney et al. 2020), they do not always increase actual physical activity (Romeo et al. 2019).

Scholarship on second-generation technologies such as smartphones and wearables only burgeoned in 2013, indicating that the field is still relatively young and has much room for deeper exploration (Müller et al. 2018). A systematic review of research on mobile health ('mHealth') apps found that the vast majority

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of studies reported on the inputs that go into building the apps, while few explored the related human factors explaining and justifying app features and uses (Chib and Lin 2018). Shifting the research focus to a more user-centric one, vis-à-vis a tecno-centric one, can potentially improve the effectiveness of health ICTs for users. Understanding the socio-psychological mechanisms of app features and users can support targeted ICT interventions that more effectively motivate health behaviour.

1.1. Role of feedback in motivating behavior change in the individual

Several theoretical models suggest that change in health behaviour happens in stages. The precaution adoption process model (Weinstein and Sandman 1992), the transtheoretical model (Prochaska and Velicer 1997), and the knowledge-attitude-behaviour continuum (Bettinghaus 1986), propose that behaviour change begins with awareness, contemplation, or knowledge. According to these models, behaviour change begins at the cognitive level. In the context of physical activity, misconceptions that one is sufficiently active pose a barrier to engaging in more physical activity (van Sluijs, Griffin, and van Poppel 2007). Feedback on actual physical activity levels can reverse inaccurate self-estimations (Watkinson et al. 2010) and facilitate the process of behaviour change.

Beyond creating awareness, feedback allows for behavioural adjustments during goal pursuit. The test-operate-test-exit (T.O.T.E.) feedback loop (Miller, Galanter, and Pribram 1960) is one of the central ideas that describes how feedback influences behaviour change. When people perform an action, they test it and receive feedback from the testing. Then they make operational changes and adaptations, test it again, receive feedback again, and make further changes. The process is iterative, repeating until people arrive at their desired goal, at which point they exit the loop. It is fundamentally important to receive personalised feedback on performance so that people can match their performance against their goal and then make adaptations to arrive at it.

Health ICTs such as fitness trackers utilise behaviour change techniques such as goal-setting, self-monitoring, and feedback on behaviour (Chia, Anderson, and McLean 2019). The quantification of users' personal health parameters gives users the opportunity for objective self-assessment (Appelboom et al. 2014) and allows for measurable goals to be pursued (Lupton 2013). Fitness trackers afford users real-time continuous monitoring (Kamišalić et al. 2018) and easy maintenance of personal records (Hoy 2016). While the majority of users particularly appreciate the immediacy of real-time feedback, they also perceive the virtue of long-term ipsative feedback accumulated by fitness trackers (Maher et al. 2017). This form of self-referent feedback allows users to view their past records and observe the discrepancy between their behaviour patterns and their goals, and motivates them to close that gap (Lyons et al. 2014). Recent reviews on the applications of fitness tracking attest to its effect on objective measures of physical activity (Brickwood et al. 2019) and physiological indicators (Yen and Chiu 2019).

1.2. Older adults' use of health ICTs

A review of studies evaluating health ICTs for older adults showed that they were able to successfully use the technologies (John and Fallavollita 2020). Older adults demonstrated high compliance rates of more than 75% in intervention studies that required them to wear fitness trackers or pedometers (Ehn et al. 2018). Post-intervention surveys confirmed older adults' acceptance of apps (King et al. 2013). The hurdles for adoption are decreasing and the prospects of positive outcomes are promising.

Beyond adoption, intervention studies testing the effects of health ICTs on older adults showed a range of positive outcomes. A meta-analysis of 22 digital interventions (e.g. websites, mHealth, and exergaming) for motivating older adults' physical activity showed that technology can significantly increase physical activity and reduce sedentary behaviour (Stockwell et al. 2019). Further, the use of mHealth technology among older adults has shown promise for improving health behaviours and managing chronic diseases (Changizi and Kaveh 2017).

Interventions to increase physical activity of older adults were more effective when they included self-monitoring (Conn, Valentine, and Cooper 2002), perhaps because older adults are motivated to engage in self-monitoring (Schlomann et al. 2016). ICTs that give older adults personalised feedback on their activity levels significantly increased physical activity as compared to control groups (Kawagoshi et al. 2015). In particular, the use of fitness trackers increased their awareness of activity levels, though motivation and behaviour effects varied between participants (Ehn et al. 2018). Fitness tracker use coupled with a training programme saw significant health improvements among older adults (Steinert et al. 2018). Despite positive outcomes, fitness tracker interventions for older adults were relatively sparse in comparison to those for younger age groups. The former kinds of interventions have tended to focus on the supervision of older adults in management of frailty and chronic diseases, which downplays the ability of fitness trackers to elevate the agency of older adults through functions such as self-monitoring (Vargemidis et al. 2020).

1.3. Based on a larger mixed-methods study

More research is needed to test the effectiveness of fitness trackers in motivating physical activity among older adults. To this end, we conducted a field experiment to test the efficacy of feedback from fitness trackers (Lin, 2020).

One of the main findings from multivariate analysis of the data was that the participants who were given feedback from fitness trackers were comparatively more consistent in meeting the daily step thresholds of 7,500 steps and 10,000 steps than those who did not receive feedback. However, the feedback intervention did not have a significant effect on other metrics of physical activity, namely, mean and median steps and hitting 15,000 steps daily. This suggests that the linkage between feedback and behaviour change is not straightforward and the outcomes may depend on individual and contextual factors.

It is unclear which behaviour change techniques in fitness technology motivate physical activity (Sullivan and Lachman 2017). The findings from the field experiment highlight that personalised feedback drives certain outcomes of physical activity and suggest that goal-related factors play into the effect of personalised feedback. Several studies attest to the positive effects of receiving feedback from fitness trackers (Brickwood et al. 2019; Yen and Chiu 2019). However, the mechanisms at work in this human–computer interaction remain elusive. We, therefore, pose the following questions:

> RQ1: How do older adults use feedback from fitness trackers in monitoring their physical activity?
>
> RQ2: How does this motivate physical activity?

Our analysis of the quantitative data provided a general sense of participants' behaviour but it lacked deeper insights into their reasons and the justifications for their behaviour. A qualitative study can supplement the quantitative by listening to their accounts of how feedback from fitness trackers played into their physical activity.

2. Method

This paper reports the qualitative portion of a larger mixed-methods study, which included a 12-week field experiment. In the experiment, we examined the roles of fitness feedback via fitness trackers as well as interpersonal influence from spouses in encouraging fitness activities. The study was approved by the Institutional Review Board at Nanyang Technological University.

After conducting the experiment, we invited a subgroup of participants for semi-structured in-depth interviews, which is the research material of present interest. In the interviews, we focused on the effect of fitness tracker feedback on motivating physical activity. The interviews were conducted using an inductive approach. Following the flow of the conversation, the interviewer made decisions on which responses required further probing and which themes required deeper development. Thus, research questions guiding the interviews were emergent as was the analysis of the material (Glaser and Strauss 1967). This approach helped us address the overarching aim in an in-depth manner.

2.1. Sample

We recruited participants from 14 organisations in Singapore that engaged with older adults, circulated the recruitment poster on social media, and distributed hardcopy and softcopy posters to students and staff at our institute. The participants had to be between 54 and 72 years old, be capable of unassisted physical activity, be able to read and understand basic English, and own an iPhone or Android smartphone with Bluetooth capabilities to link it with a fitness tracker. In addition, for the duration of the experiment, participants needed to commit themselves to using only the fitness tracker we provided. The age range defined in the inclusion criteria is aligned with the baby boom age range in Singapore. It constitutes a sizeable proportion of the local population and creates an impact on aging demographics locally (Sharmistha Roy 2014). The age range also includes people moving up in age to where they face the risk of increased health issues.

We selected interviewees based on their performance in the experiment. They were either high or low performers and participants who showed inconsistent activity patterns. Selecting these specific types of interviewees allowed us to gain insight into the various spectrums and patterns of their behaviour. We contacted them and scheduled an interview slot at a convenient time for them. The interviews were held at our institute and were conducted in October 2019, two months after the experiment ended. We obtained informed consent from each interviewee before the interview and voice-recorded all interviews. We conducted interviews until they stopped producing new themes, suggesting we had reached theoretical saturation (Glaser and

Strauss 1967). At that point, we had interviewed 22 of the 208 individuals who participated in the experiment. Upon completing the interview, interviewees each received a token of appreciation of SGD30 in grocery shopping vouchers.

We assigned the participants pseudonyms with the suffix ‘bert’ for males and ‘belle’ for females. Those with the same prefix were part of a married couple. Since the interview material was gathered after the experiment, it was possible to put interviewees’ comments in the context of their performance during the experiment phase. Thus, after coding the interview data, we sorted the transcripts based on their step performance in the experiment, then grouped the interviewees into quartiles for ease of ranking the interviewees’ level of activity. This allowed us to link the relevant quantitative data to the qualitative responses and understand how their subjective experience may have translated into different physical activity outcomes. Those who met the 10,000-step threshold least often were in the lowest quartile (Q1) and those who met it most often were in the highest quartile (Q4). This sorting was useful for interpreting the qualitative responses with respect to their step performance. Table 1 lists the interviewees by pseudonym, age, sex, mean and median numbers of daily steps, percentage of days with at least 10,000 steps, and performance quartile.

2.2. Analysis

The first author performed a thematic analysis (Braun and Clarke 2006) on the interview transcripts using the RQDA tool (Huang 2018). The primary-level a posteriori coding was followed by secondary-level analysis and further interpretation of the data. The analysis was conducted using the constant comparative approach (Glaser and Strauss 1967; Boeije 2002), where new data was compared with old data, and matched against the relevance to the interview foci. The themes were distilled and redefined up to the point of saturation where no new themes emerged from the data.

For quality control of the data, the interviewer personally checked all the transcripts of the interviews against the audio recordings before any data analysis took place. For improved data validity and reliability, two of the authors met at regular intervals to review the interview material and the coding of the data, as well as to discuss emergent themes. In addition, the interviewer also kept memos of all the interview sessions and the data analysis process (Tracy 2013).

3. Findings

The analysis of the material helped to clarify the effect of feedback from the fitness trackers. The emergent themes resolved how the interviewees used the feedback from fitness trackers vis-à-vis their physical activity. From the responses of the interviewees, we distilled four themes to explain the role of feedback from fitness trackers in the physical activity of older adults. These include cognition, emotion, action, and intuition. Further, we grouped these effects into two levels of progression, from the internal to the external.

Table 1. List of interviewees.

Pseudonym	Sex	Age	Mean steps	Median steps	Days >10000 steps	Performance quartile
Dilbert	M	61	5400.5	5290.0	0.00%	Q1
Cobelle	F	55	7073.2	7321.5	7.81%	Q1
Berbelle	F	55	6030.9	5202.5	12.22%	Q1
Cobert	M	56	7115.4	6891.0	21.35%	Q1
Kristabelle	F	64	7679.8	6578.0	26.09%	Q1
Hallebelle	F	56	7899.1	6955.0	26.97%	Q1
Furbelle	F	65	8826.3	7591.0	30.68%	Q2
Ottobert	M	64	8918.1	9004.0	30.77%	Q2
Jerbelle	F	55	8975.7	9032.0	31.87%	Q2
Lobert	M	69	9244.0	9086.5	43.18%	Q2
Monbelle	F	56	9684.7	9982.0	47.73%	Q2
Monbert	M	60	10983.0	10758.5	56.82%	Q3
Norbelle	F	62	11003.2	10523.0	58.24%	Q3
Kristabert	M	70	10726.5	11181.0	59.34%	Q3
Jerbert	M	62	11657.2	10740.0	67.39%	Q3
Gilbert	M	57	10406.0	10269.0	67.42%	Q3
Ipbert	M	58	13034.6	12394.5	71.74%	Q4
Erbert	M	64	11547.4	11191.0	72.22%	Q4
Ashbert	M	56	11749.4	11423.0	72.53%	Q4
Dilbelle	F	56	11472.4	11510.0	72.94%	Q4
Lobelle	F	57	11721.7	11646.5	73.33%	Q4
Norbert	M	72	10334.4	10774.0	82.80%	Q4

Note. Those in Q1 met the step thresholds less often than those in Q4.

3.1. Cognitive

Analysis of the data revealed that interviewees engaged with the feedback and processed the information mainly along two parallel paths. Whereas some interpreted the feedback merely at its face value, others made meaning of it in relation to a goal. The latter interviewees were cognitively more engaged with the fitness tracking data.

Overall, interviewees reported that the feedback primarily provided insight on performance. Ottobert (Q2) noted that the fitness tracker was 'very useful to help people check how much they have done for the day, how many steps they have done, to bring awareness to them'. Cobert (Q1) specifically noted the difference between having a fitness tracker and not having one, 'At least we can track the steps that we move and can track our pulse, our heartbeat. Without this, there's no guide at all […] you don't know where you are, how many steps per day'. The basic awareness of activity levels was a key function mentioned by interviewees.

Some interviewees engaged with the feedback at a superficial level. They were aware of the objective measurements of their activity levels, but their comments indicated that there was hardly further engagement with the data. This was usually the case when they had ingrained habits and were not looking to make changes in their lifestyles. Referring daily to the fitness tracker, Dilbert (Q1) learned that he averaged approximately 5,000 steps per day. However, he did not feel that he needed to adjust his routines to walk more. Similarly, Cobert (Q1) said:

> We will still do as per normal routine. It's just that we want to know. Last time you don't have [a fitness tracker], now you have, it's good to know what you've been doing, what your lifestyle is, your pattern is. It doesn't push us at all, no.

Cobelle (Q1), his wife, concurred, 'Yes, it is just only data that we collect, [to know] what's your activity for the day'. Berbelle (Q1) also explained why the feedback had only informational value to her, 'It's good to have data […] It's for your own knowledge. Just see for fun […]. You know what you're doing […] you are not doing anything that is something outside the usual activities that you participate [in]'.

In contrast to these comments, some interviewees said that the feedback brought about an added dimension of awareness. For them, it was not simply about knowing the number of steps they walked but evaluating how they were doing in comparison with their personal fitness goals. These interviewees made sense of the data by matching it against a goal they had set for themselves. For example, after receiving the fitness tracker, Erbert (Q4) began to walk more 'systematically'. He explained:

> Now [I am] very systematic because I want to see my achievement. Last time […] I just walk […] I may walk more, I may walk less, I don't know. That's why now […] I wear [the fitness tracker] consciously. Everywhere, I wear. I want to make sure every day I have the record […] In the past, if I don't wear [a] tracker, I don't have the numbers, then how do I know how many steps I walked? But now, I see, [I know it is] not enough.

Jerbelle (Q2) attested that the feedback from the fitness tracker made her more aware of what she needed to do. Hallebelle (Q1) explained that being able to see her step count on the fitness tracker was useful since: 'If I want to achieve something, I need to know where I stand and things like that. If I set a goal, I must know where I stand […] so to see [feedback on the fitness tracker] is definitely important'.

3.2. Affective

The second theme had to do with interviewees' emotions, which were mostly positive. No interviewee reported feeling negative emotions from their interactions with the feedback. Interviewees who experienced affective effects noted that these emotions were triggered when they checked their own progress or when the device gave them automated congratulatory messages or reminders to move.

Interviewees who referred to their fitness trackers and saw that they had clocked a certain number of steps reported feeling motivated and encouraged. Hallebelle (Q1) said, 'I think it keeps me motivated knowing how many steps I have done for a day'. Similarly, Ottobert (Q2) noted that:

> I look at it, "Wow, not bad, I have achieved about ten thousand steps." […] With the number stated here, it encourages me to know how much exercise I have done for the day. […] If I see ten thousand, it really encourages me. If I see three thousand, maybe it's more of a prompter, a prompter to tell me, "Today, you have not done much walking."

Some of them felt comforted by the data. They were happy to see that they had achieved health parameters that they considered to be good enough or better than they expected. Jerbert (Q3) was pleased with his heart condition, 'I start looking at how is my heart condition, where am I for my age, actually, I'm quite surprised that I'm pretty good'. Lobelle (Q4) was also satisfied with her activity levels, 'I thought it's very good to let us have the opportunity to know how active we are. At least I know, 'ten thousand', that means my lifestyle is quite okay, not too sedentary'. Monbert (Q3) appreciated the weekly reports showing his ipsative progress, 'Yes, unexpectedly you did something very well, you praise yourself, 'Wow, I did it.' […] It gives you encouragement when you know what your level is'.

Automated prompts also brought about positive emotions. The Fitbit device can be configured to prompt users to take 250 steps every hour for a specified number of hours each day. For every hour with 250 clocked steps, the user receives a star in the app. Some interviewees were encouraged by this feature. Norbert (Q4) reported feeling motivated by the good feeling of winning those stars and paralleled it to how he used to study, 'That's how we learned to read in school. We got like one star every day when we managed to write a new letter or something like that'. The Fitbit device also features a congratulatory prompt for users who achieve their step goal for the day. Kristabelle (Q1) described how she felt about this feature with excitement, 'It will boom. It's just the thrill. It's a cheap thrill, really. You don't move, it will push you, "Go, go, go, go, go!"'

3.3. Conative

The third theme was about reacting to the feedback and making behavioural changes. The material shows that the move from the internal psychological level to the external behavioural level was contingent on the interviewees' goal-related decisions. Their goal progress was related to three factors: (1) the goal they had in mind, (2) their level of goal-orientedness, and (3) their perceived behavioural control in relation to arriving at their goals. Based on these factors, feedback from the fitness tracker could lead to varying behavioural changes or none at all.

3.3.1. Goal

First, goal-related decisions were primarily guided by personal goals. Perhaps in line with the popular notion of step-counting (Tudor-Locke et al. 2011; Yao et al. 2019), most interviewees reported having 10,000 steps as their daily goal. However, there was some variance. Indeed, some participants were quite advanced in their understanding of step counts. For example, Hallebelle (Q1) described an empirical finding (Lee et al. 2019) she read in the news that taking 4,400 steps each day was significantly associated with lower mortality rates among older women. As such, Hallebelle (Q1) had a two-tiered goal in mind:

> I set the target at ten thousand, I think it is preset at ten thousand, so I would try to hit ten thousand […] But, from some research I know ten thousand is not the real figure that we should target. Actually, four thousand four hundred is good enough. So at least now I know that if I cannot hit ten thousand, I try to do at least four thousand four hundred per day. I think knowing what is my target and knowing whether I'm there or not does help, so if I'm not there yet, then I'll try to strive […] If I can, I hit ten thousand. If not, then it'll be four thousand four hundred.

The varying step count goals we observed among interviewees suggest that some participants in lower quartiles could also be highly engaged with their fitness trackers, but they justified a lower daily step count after having done some extra research. The goals that interviewees had in mind influenced their decision to make behavioural changes as they adjusted their activity levels around their goals in empowering or limiting ways, depending on their orientation to the goal.

3.3.2. Orientation to goal

Next, behaviour change was related to how much interviewees oriented themselves towards their goals. Some had a goal but were less oriented towards achieving it. Those participants tended to report more internal effects related to cognition and emotion but achieved relatively lower levels of behaviour change.

In contrast, some goal-oriented individuals worked resolutely toward achieving their goals. Erbert (Q4) described how being goal-oriented influenced the effect of feedback on his activity levels, 'I think it is kind of like an achievement that you can see […] you want to achieve the target. And in a way, it becomes like part of me. […] I've become very conscious of these types of numbers'. Kristabert (Q3), Monbert (Q3), and Gilbert (Q3) reported similar sentiments of wanting to achieve their targets. Gilbert (Q3) said in an illustrative manner, 'Every day [you] must go and hit [the] target […] sometimes almost, almost there! Push here, push there, to achieve the target'.

Among those who were goal-oriented, some perceived their goal as a cap with which they were content. Others perceived their goal as a baseline and wanted to engage in more physical activity beyond their goals. The former worked towards reaching their goals and were inclined to stop once they hit it. Gilbert (Q3) claimed that he tried to hit his daily target, 'no more, no less'. Likewise, Jerbert (Q3) tended to decide against further activity if he had hit his goal for the day:

> In a way, it also demotivates you from doing more. Once you achieve it, ah, that's enough for the day. That's it. So, it can be demotivating sometimes. So, I blame it on that, that I'm not doing more. […] In a way, it's demotivating […] the device is good, but it can also be a disincentive. Once you meet that requirement or it shows that you've met the requirement, you tend to stop, not do more, so that can be an issue as well.

Other interviewees were differently oriented to their goals. While Norbert (Q4), Monbert (Q3), and Monbelle (Q2) had 10,000 steps per day as their goal, they treated it more as a baseline than a cap. As Monbert (Q3) put it, 'We try to aim and aim higher. So, [at a] minimum we'll try to hit ten thousand steps every day. At times, you can go more, fifteen [thousand] to twenty thousand, better still'. Norbert (Q4) wanted to exceed his baseline goal only within comfortable limits. He was a little more cautious as he was looking to build a lifestyle that he could maintain in the long run:

> I want to have more than ten thousand […] So, I try to keep to ten [thousand] to eleven thousand […] If I do that, I'll be like, "Okay, I've done eleven thousand already, I don't have to go for another walk in the evening," because it's not like outperforming is the point here, it's more like to continue, not to give it up. [If] you walk like crazy for some weeks […] you fall back to your old pattern. I try to keep it at a steady level of effort and sort of keep it there, for the long term.

3.3.3. Perceived behavioral control

Finally, behaviour change was related to the perceived ability to achieve goals. Interviewees' perceived control over managing barriers such as limited time and physical comfort levels influenced decisions to make behavioural changes.

Cobert (Q1) had a goal of 10,000 steps but did not push himself to meet it because he had limited time due to work commitments. He said, '[The feedback is] good to know. Unless you have time, then you push yourself'.

Some female interviewees preferred to defer to physical comfort levels when exercising. Hallebelle (Q1) said, 'I think I listen to my body. When I feel that I cannot take it, I will slow down, I don't care what it [the fitness tracker] says'. In a similar vein, Berbelle (Q1) mentioned that she might increase her step goal if she had been achieving it for some time. However, the revised goal would be something she perceived she could easily and comfortably attain, and she would work within the comfort zone of her fitness levels in trying to achieve it.

3.3.4. T.O.T.E. Adjustments

After processing all or some of the goal-related decisions above, there were interviewees who felt that the feedback from the fitness tracker eventually led to an increase in their physical activity. For example, Dilbelle (Q4) said that with the fitness tracker, she made a conscious effort to clock more steps. Erbert (Q4) also experienced the same effect; the fitness tracker made him more conscious of his activity levels, and he found himself exercising and walking more regularly. Monbert (Q3) illustrated this point when he said, 'Since I've been using this Fitbit, I start[ed] moving, walking more and more'.

Interviewees made actual behavioural changes based on goal-related decisions. That is, they would not simply note the feedback, but they also made behavioural changes in line with their goals. The data are consistent with the process of a T.O.T.E. loop (Miller, Galanter, and Pribram 1960), where interviewees tested their performance against their goals to determine if they had achieved them. When they came up short, they made adjustments in their behaviours toward achieving their goals. In this situation, interviewees matched their measured activity levels against their goal (test), made activity adjustments (operate), matched themselves against their goal again (test), and repeated the process until they achieved their goal (exit).

The feedback tools afforded by the fitness tracker functioned as behavioural nudges in facilitating this testing process. Specifically, interviewees reacted to three different types of nudges: (1) ipsative records, which involved comparing themselves with their own past records and led to eventually making future adjustments in order to meet an averaged goal; (2) real-time measurements, which involved checking their current activity levels and working towards a daily goal; and (3) automated prompts from the fitness tracker, which came in the form of vibrations reminding them to move. Each of these functions served as a testing tool for interviewees to see how they performed against their physical activity goals, thereby informing them of the adjustments they needed to make.

3.3.4.1. Ipsative records. Interviewees utilised ipsative records collected by fitness trackers as a testing tool. They referred to the accumulated records at the end of a day or a week and made future adjustments for meeting an averaged goal. For example, when, at the end of the day, they realised that they had not met their activity levels, they would try to make up for it the next day to compensate for the missed goal. Furbelle (Q2) said:

> The steps will tell whether I do have enough exercise on that day. Sometimes maybe, [I am] too lazy, if I don't go out, I stay at home, wow, the steps show that it's so low. Then I'll make sure the next day, I really go out to walk or play [sports], at least.

In a similar way, Lobelle (Q4) would check her records at the end of the day and if she didn't meet her goal, she would tell herself, 'Oh, today [I] didn't achieve, maybe tomorrow I walk a bit more'. Lobert (Q2) had a similar experience, whenever he realised he did not meet his goal, he would tell himself, ‘Maybe another day I should do more to cover [patch] it up’.

3.3.4.2. Real-Time measurements. Another way the feedback from fitness trackers served as a testing tool was by providing real-time measurements. This allowed interviewees to make immediate adjustments in working towards their daily goals. This could happen in terms of measurements of step count or heart rate intensity.

Erbert (Q4) would refer to the step count measured in real-time by the fitness tracker and gear his activities towards meeting his daily goal. He illustrated how these real-time measurements informed his daily activities:

> “Now only six thousand [steps], should I walk some more today?” Then I will say, “Ok, let me go out and achieve my target.” […] Last time, I walked just aimlessly. […] I feel that now there’s something that reminds me to do it [… The fitness tracker] disciplines me, that I must fulfill the target I set for myself […] motivates me to achieve my target. Along [with] the motivation, it becomes [a] discipline that I must do it.

Adjustments in activity intensity could go in positive or negative directions, but both served to adjust heart rates into the recommended range. Lobelle (Q4) increased the intensity of her walks according to the real-time measurements of her heart rate on her fitness tracker. She would tell herself, ‘Yes, walk faster, so that my heart can pump higher, faster, and then I can clock the activity’. Norbelle (Q3), on the other hand, used the information in another way. She controlled the pace of her hikes to ensure it stayed within the safe range, ‘When I was hiking, I was feeling breathless, so I was just checking my heartbeat all the time to make sure that it is within a certain range’.

3.3.4.3. Automated prompts. The third testing tool provided by the fitness trackers was the automated prompts that nudged the users. Again, interviewees commented that adjustments could be related to heart rate intensity or step count. Specifically, the fitness tracker would vibrate whenever the user’s heart is beating too vigorously beyond the safe zone. It would also alert them whenever they had not yet clocked 250 steps per hour during designated active hours.

Some interviewees reported behavioural changes motivated by the hourly activity feature. Responding to this function nudged interviewees out of being sedentary for prolonged periods of time. Hallebelle (Q1) said this function was helpful for her, ‘It would buzz, so I would just get up and complete my two-fifty [steps]’. Norbert (Q4), who had led a sedentary lifestyle since retirement, became more active after responding to these automated prompts. He and his wife, Norbelle (Q3), described how this feature worked for Norbert.

> Norbert: I want to try to make two hundred and fifty steps, to get my stars.
> Norbelle: He wants the nice stars to boom […]
> Norbert: [If] I get an alert […] I have to get up and walk.
> Norbelle: He is very religious about it. He is so religious about it.
> Norbert: Like now [during the interview], [if] I get it (the prompt from the Fitbit), I have to go out.
> Norbelle: When they prompt you, you really get up and walk […] it’s an alarm […] I’m just wondering, if you don’t wear this anymore, will you get up and walk every hour?
> Norbert: No. I will forget. Because I’ll go into this or that and find it interesting, so I sit down and work on something that I feel I need to solve today and then I would forget about time.

Other interviewees used the automated prompts for adjustments of intensity, to ensure their heart rates remained within the safe range. Gilbert (Q3) said that the fitness tracker would vibrate whenever he got too excited and his heart pumped too quickly, ‘The heart pumps very fast, then the watch will tell me, “Slow down, relax. Cool down!” […] I don’t feel it, but the watch tells me, “Relax, relax, you are too excited, your heartbeat is very fast.”’ […] It will vibrate’.

3.4. Intuitive

We noted a fourth theme, which involved interviewees integrating the feedback into their lifestyles and restructuring their routines to accommodate activities necessary for them to reach their goals. Some might even no longer require feedback from the fitness tracker since they had learned the specific elements of their activities that helped them reach their goal. In this manner, the feedback from fitness trackers led some interviewees towards lifestyles that intuitively met their goals.

Through the feedback, interviewees learned that certain activity patterns (e.g. specific routes or durations) meant clocking a certain number of steps, so they restructured their lifestyles accordingly. By adhering to these new patterns, they knew that they would hit their goal. For example, Erbert (Q4) learned that he would clock 5,000 steps by walking out for breakfast and then walking back home. To meet his daily target of 10,000 steps, he would have to do the same for lunch. Ipbert (Q4) noted that with his walking pace, he had to walk 2 hours every day to clock 10,000 steps, so he adjusted his lifestyle to accommodate a 30-minute walk after breakfast, a 30-minute walk after lunch, and a 1-hour walk at night. If he carried out these three walks, he knew that he would hit his daily goal. He no longer needed to refer to the fitness tracker to inform his behaviour because he had already adjusted his lifestyle towards meeting his activity goals. Nonetheless, he continued using the fitness tracker, 'I know I'm consistent, just want to see how well I'm doing today on my steps, that's all […]. I believe now I'm quite consistent […]. Walking is part and parcel of my daily life'.

Norbert (Q4) responded to automated prompts to maintain his minimal hourly activity of 250 steps. In progression, he believed that if he continued responding to these prompts and made it habitual, he would no longer need them in due time:

> The longer I keep using this […] and get up like every hour to walk, it becomes a habit, so I don't need this [fitness tracker] to do it. I think if I continue for one year then I will just feel like something is wrong if I don't get up and walk. So, I will probably not need it, but it's good to have it as a reminder still.

This final theme hints at some degree of nirvana, where users are enlightened by the feedback from the fitness tracker until they no longer need to rely on the fitness tracker to inform their behaviour. Instead, they refer to it only for the gratification of knowing they hit their goals. By this time, in place of conative action, habitualized intuition takes control.

4. Discussion

This study considered the effects of personalised feedback from fitness trackers in motivating physical activity among older Singaporeans. We noted four themes reflecting different stages of motivation, namely, cognitive, affective, conative, and intuitive. We grouped these themes with respect to internal and external outcomes and derived a totalising process model that explains the role of feedback in motivating physical activity. This explorative model incorporates the effects of feedback and the ways interviewees reacted and adapted in this instance of human–computer interaction. We present this model in terms of two levels that suggest how feedback may support the translation of thoughts and feelings into actions and habits.

The first level contains effects that took place internally within interviewees. To varying degrees, interviewees engaged with feedback cognitively. The objective measurements reflected on the fitness tracker and the app increased their awareness of their activity levels. Upon gaining this awareness, some interviewees reported positive emotions such as feeling encouraged or comforted, while others did not report feeling any emotion. None of the interviewees reported negative emotions. Regardless of whether they experienced emotional effects, all interviewees nonetheless made goal-related decisions, which determined their progress to the level of external effects.

Some interviewees reported that they progressed to the second level, where effects could be observed externally. They used the feedback to inform personal behavioural change. These actions, however, were contingent on the goal they had in mind, how oriented they were towards that goal, and how much control they felt that they had over their own behaviour. With successful behavioural adjustments, some users also used the feedback to restructure their lifestyles in a way that allowed them to intuitively achieve their goals. Figure 1 graphically summarises this process and the related mechanisms. In the right column, we included quotes that typify interviewees' experiences at each stage.

Interestingly, while the fitness tracker communicated with interviewees mainly through vibrations and a few words that appeared on the small display screen, some interviewees internally translated these prompts into human language, indicating interaction between the user and the device. For example, Gilbert (Q3) said that his fitness tracker was telling him, 'Relax, relax, you are too excited, your heart beat is very fast', and Kristabelle (Q1) felt the fitness tracker 'push' her when she was not moving, as if saying to her, 'Go, go, go, go, go!'

4.1. In the context of the larger study

Interpreting the qualitative responses with reference to interviewees' level of measured activity in the experiment allowed us deeper insight into how our process model (see Figure 1) translated to actual behavioural outcomes.

Interviewees who had lower performance scores in the experiment (Q1 and Q2) mainly reported effects that were focused on the cognitive stage. In fact, many of them did not see a need to increase their physical activity as they were entrenched in certain lifestyles, routines and patterns. Thus, the feedback became merely a source of information for them and its value was superficial. Interviewees in the higher quartiles seldom dwelled on the cognitive aspects of their fitness tracking, but when they did, they tended to show more engagement with the data. Specifically, they used the feedback for more than its face value by considering how the data was related to their goals and goal achievement.

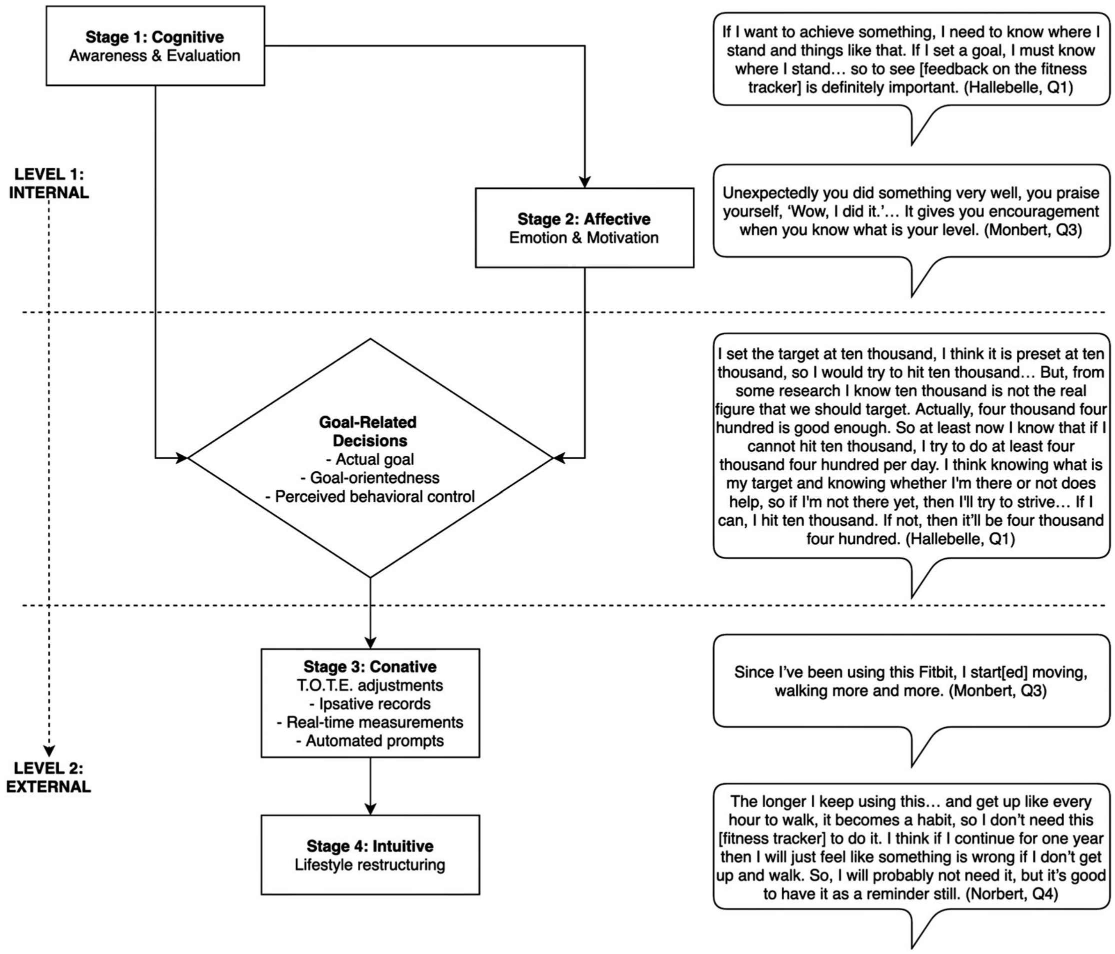

Figure 1. Process model of the role of feedback from fitness trackers in motivating physical activity among older adults.

While interviewees from all quartiles reported experiencing affective motivation from their interactions with the feedback from fitness trackers, we observed that those from higher performance quartiles (Q3 and Q4) more frequently reported experiencing positive emotions. In contrast, interviewees from the lower performance quartiles (Q1 and Q2) seldom reported feeling any emotion about the feedback.

When it came to the transition between the internal level and external level, it was even more apparent that participants from different quartiles diverged in their decision-making processes, particularly with respect to goal orientation and perceived behavioural control. The high performers (Q3 and Q4) more often reported being oriented towards their activity goals, while the low performers (Q1 and Q2) were less motivated to reach their target and had lower perceived behavioural control over temporal and physical limitations.

Most interviewees reported having a 10,000-step goal, and the high performers were motivated to reach this goal. However, some of them also used their goal as a cap. Perhaps such ideas explain why feedback on performance can result in negative effects at times (McDermott et al. 2016). For example, Jerbert found the feedback to be a disincentive, as he became disinterested in walking further after hitting the 10,000-step goal. The qualitative and quantitative (Lin 2020) findings converge on the point that the effect of feedback on physical activity is largely driven by goal-related decisions.

At the conative stage, behaviour change happens when interviewees adjust their physical activity after receiving feedback. Interestingly, more interviewees in the lower quartile reported using ipsative feedback to make behavioural adjustments, while more interviewees in the higher quartiles reported using real-time feedback to the same end. This suggests that real-time feedback may be more effective than ipsative feedback in driving physical activity. This may be because the immediacy of the feedback allows more immediate responses. It may also be because it involves interviewees comparing themselves with a fixed goal instead of measuring up to their past performances. Less frequently, interviewees noted the effect of the fitness trackers' automated prompts, but those who mentioned it said that it was useful and resulted in positive behaviour change, as responding to the automated nudges pushed them out of a sedentary state. We did not note any difference between high and low performers on this point.

Finally, only the top performers (Q4) progressed to the fourth stage of intuitive behaviour, where feedback informs a restructuring of their lifestyle in a way that they intuitively achieve their goals after habitualizing the actions. Very few interviewees had arrived at this stage of the process model. Some were getting close to or had already 'weaned off' the effect of feedback by cementing changes in their daily routines that allowed them to consistently meet their step goals.

Delving deeper, the effect of feedback from fitness trackers appears to be goal-related. We see that interviewees make goal-related decisions before progressing from the internal level (cognition and emotion) to the external level (action and intuition). In other words, without a goal in mind, feedback alone will probably be ineffective. The T.O.T.E. feedback loop (Miller, Galanter, and Pribram 1960) works on a similar assumption. The current findings also affirm the ingredients of self-regulation that Baumeister and Vohs (2007) identified: standards, monitoring, self-regulatory strength, and motivation to meet the standard. Without a standard to mark themselves against, people would not know how to make behavioural adjustments. The feedback process model derived from the qualitative results (see Figure 1) further incorporates the T.O.T.E. feedback loop to explain how specific types of feedback from the fitness trackers – namely, ipsative records, real-time measurements, and automated prompts – work as tests for users to use the feedback to inform behavioural changes. We note that the model is explorative due to the nature and the scope of the study, and suggest that future studies can test the feedback process model and find how far the three types of goal-related decisions – namely, the actual goal, the level of orientation to the goal, and the perceived behavioural control – explain the effect of feedback.

The findings also illuminate how the real-time feedback afforded by modern technology has the potential to be a game changer when compared to traditional forms of feedback such as ipsative and normative feedback (DiClemente et al. 2001). In this context, the real-time feedback displayed on the device was perhaps the most used and most effective.

The model arising from this study identified the different stages of motivation from feedback, and the goal-related mechanisms that drive internal effects into external behavioural change. By explaining how and why feedback motivates physical behaviour among older adults, this study gives us a glimpse into the black box of feedback from fitness trackers and elucidates the promise of mHealth for older adults.

As is the nature of qualitative studies, we acknowledge that the generalizability of the results is limited. We do not know if the same model can be applied to all users of fitness trackers. However, we feel that the fine-grained data gathered from this group of interviewees is robust enough for us to form a holistic model that suggests how fitness tracking had influenced the physical activity of these interviewees. This provides some understanding of why and how tracking interventions sometimes motivate physical activity and sometimes do not. Future studies can test this model in a quantitative context to assess its generalizability among larger and more diverse groups of fitness tracker users, including those from different cultures and national contexts.

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Ethics approval

The ethics committee of Nanyang Technological University approved this study (IRB-2018-12-016). Interviewees signed informed consent forms before participating in the study.

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