DISSERTATION

WEARABLE FITNESS TRACKERS IN PHYSICAL ACTIVITY RESEARCH: ACCURACY ASSESSMENT AND EFFECTS ON MOTIVATION AND ENGAGEMENT

Submitted by

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ABSTRACT

WEARABLE FITNESS TRACKERS IN PHYSICAL ACTIVITY RESEARCH: ACCURACY ASSESSMENT AND EFFECTS ON MOTIVATION AND ENGAGEMENT

Although physical activity (PA) is the single most impactful behavior in reducing disease risk and all-cause mortality, a majority of adults do not meet physical activity recommendations of 150 minutes of moderate PA or 75 minutes of vigorous PA per week.[1] To boost PA levels in adults, non-profit organizations, life and health insurance companies,[2] corporations, and University wellness programs[3] have implemented interventions using wearable fitness trackers (WFTs). Over 100 million of these small, often wrist- or hip-worn devices were sold in 2018, a number that will double by 2022.[4] Unfortunately, it is unclear as to how WFTs affect PA behavior. Further, a majority of WFT users abandon the devices within a few months of acquisition.[5]

It is largely unknown how WFTs influence an important mediator for PA, motivation, in current and former users. In this series of dissertation studies, I've chosen the Self-Determination Theory (SDT) as a framework to describe motivation for PA. The SDT posits that humans have three psychological needs: autonomy, competence, and relatedness,[6] and when these needs are fulfilled, they are able to move along a motivation continuum from more controlled forms to more autonomous forms.[7]

The subtypes of motivation include the most autonomous form, intrinsic motivation, in which behaviors are undertaken purely for enjoyment.[7] Amotivation lies opposite of intrinsic motivation and occurs when a person has no intention to participate in the behavior.[7] In between

these two extremes lie four other subtypes of motivation: external regulation, introjected regulation, identified regulation, and integrated regulation.[7] Externally regulated behaviors are driven by a desire to be compliant, to conform, or to receive external rewards or avoid external punishments.[7] Introjected regulation refers to motivation that is grounded in a drive for self-control, a need to protect one's ego, or to receive internal rewards or avoid internal punishments.[7] Identified regulation of behavior occurs when the motivation is somewhat internal and is based on conscious values.[7] The most internalized form of extrinsic motivation is integrated regulation which is driven by intrinsic sources such as the desire to act in congruence with one's values and sense of self.[7]

Research indicates that persistent engagement in moderate to vigorous PA is associated with more autonomous forms of motivation.[6,8] Furthermore, features typically embedded in WFTs may facilitate the movement toward more autonomous forms of motivation for PA by the fulfillment of psychological needs.[9] For example, device features that provide feedback on the user's activity and allow for self-monitoring of behavior have the potential to enhance competence for PA.[9] Also, most WFT allow the user to choose from a variety of PA modes like swimming, dance, golf, strength training, and more, [10,11] and providing the opportunity for choice can enhance autonomy for PA.[12,13]

Theoretically, then, WFTs should support more autonomous forms of motivation for PA in WFT users. However, it is unclear whether or not WFTs actually support the development or maintenance of autonomous motivation. Also, according to a review by Sullivan and Lachman,[14] the most effective strategy to increase PA and sustain that increase is to employ multiple behavior change techniques. Therefore, I speculate that combining a WFT with another tested intervention, like motivational interviewing (MI) may result in better PA and motivation

outcomes than either intervention alone. The following dissertation describes a series of studies intended to explore the state of the literature on WFTs and MI and their effects on PA and motivation, assess the accuracy of a novel WFT device in the free-living environment, investigate the impact of WFT use on motivation and PA in WFT users and former users, and determine the effect of WFTs, MI, and the two together on PA and motivation.

In the first study, Chapter 2, I conducted a systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, an evidence-based set of minimum standards for systematic reviews and meta-analyses.[15] To review the effects of WFTs and MI based interventions on PA and motivation for PA. Whereas interventions with MI positively impact motivation for PA and PA behavior, WFTs use revealed mixed results. WFTs prove effective in supporting increases in PA among individuals not currently meeting PA guidelines, but have little impact on other populations. MI and WFTs in combination provide a promising combination of interventions to increase PA among sedentary individuals, though existing literature did not examine the effect on motivation.

In the second study, Chapter 3, I sought to assess the accuracy of a novel WFT, the Shyft STYR for use in research. This device has hardware deemed comparable to a Fitbit,[16] and estimates metrics like daily steps and Calorie expenditure. Comparing the STYR estimated metrics to the ActiGraph GT3X+, the SS grossly overestimated steps with mean absolute percent errors (MAPEs) well over 100% in some cases. It also underestimated EE, although MAPEs were much lower, ranging from approximately 24% to over 170%, although most MAPE values were on the lower end of that spectrum. The Consumer Technology Association[17] has determined that 10% MAPE is acceptable for a device to be considered accurate. As such, I

chose to use a well-known and widely studied WFT, a Fitbit, in my randomized controlled trial instead of the STYR.

The third study, Chapter 4, was a mixed-methods examination of motivation for PA and PA engagement in current and former WFT users. Current and former WFT users did not differ in the minutes of moderate to vigorous physical activity (MVPA) per week. However, current WFT users had significantly higher levels of both introjected and integrated regulation for PA and significantly lower minutes of sedentary time per week. Qualitative results showed that current users valued their WFT as a means to collect data about their PA whereas former users had concerns about data accuracy and doubted that their WFT influenced their PA engagement. Former users also felt stressed when they received feedback from their WFT about not meeting their WFT goals. Using these results, I created hypothesized models of both current and former WFT users.

The final study (Chapter 5) was a randomized controlled trial intended to test the effects of WFT, MI, the combination of both (WFT+), and PA education on PA and motivation over the course of twelve weeks. Both MI and the WFT+ conditions were associated with increases in autonomy, competence, and autonomous forms of motivation. The WFT group only increased in competence and the Education group increased in intrinsic motivation. There were no significant effects of the interventions on minutes of MVPA or steps per day. There was an interaction effect between baseline relative autonomy and group on post-intervention steps per day, suggesting that individuals with more autonomous motivation would benefit more from the WFT+ intervention whereas individuals with lower baseline autonomous motivation would benefit more from a WFT.

The combination of these studies adds a significant contribution to the literature about WFTs, motivation, and PA engagement. The results of studies three and four also beg the question: is there an ideal person for whom a WFT may be a beneficial intervention to both enhance autonomous motivation for PA and PA participation in the long-term? In Chapter 6, the complexities of investigating this question are outlined with a hypothesized model to guide future research.

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CHAPTER 1-INTRODUCTION AND AIMS

American adults are insufficiently active, despite the evidence that physical activity (PA) is the single most impactful behavior in reducing disease risk and all-cause mortality.[1] A number of organizations, including life and health insurance companies,[2,18,19] corporations, and University wellness programs[3] have turned to interventions like wearable fitness trackers (WFTs) to support sedentary and inactive individuals in increasing their daily PA. These devices are exceedingly popular among consumers with over 100 million sold in 2018, a number that will double by 2022.[4] Unfortunately, little is known about how WFTs impact PA behavior in the long-term and the majority of WFT users abandon the devices within a few months of acquisition.[5]

It is also unclear as to how WFT use affects motivation for PA. According to Ryan and Deci,[6] the developers of the Self-Determination Theory (SDT), motivation drives people to act. In SDT, motivation lies on a continuum from controlled (external or coerced) to autonomous (internal or volitional) forms. Movement along this continuum is influenced by the fulfillment of three psychological needs: competence, relatedness, and autonomy.[7] As it pertains to PA, Ryan and Deci[7] point out that more autonomous forms of motivation are associated with persistent engagement in moderate to vigorous PA.

Motivational Interviewing (MI), while not directly associated with SDT, is a person-centered form of engagement that employs a set of specific counseling techniques to encourage the assessment of one's own position on the motivation continuum. This counseling style has been recommended by health promotion interventions such as the American College of Sports Medicine's Exercise is Medicine.[20] It emphasizes empathetic listening by the practitioner to

increase relatedness and empowering the client to make decisions and take action in order to increase competence.[21] MI supports autonomy by allowing the client to voice their own motivations for and ambivalence toward change instead of having it imposed upon her by the practioner.[21]

With the continued popularity of WFTs in wellness programs and on the consumer market, it is important to understand 1) their impact on PA and PA motivation and 2) how to leverage these devices to influence PA and PA motivation on a larger scale. One potential method to improve the effectiveness of WFTs is to combine them with other interventions. According to a review by Sullivan and Lachman,[14] the most effective strategy to increase PA and sustain that increase is to employ multiple behavior change techniques. One such technique might be MI, yet the effect of WFTs and MI together has not been fully tested.

In summary, the overall objectives of my dissertation are to: explore the state of the literature on WFTs and MI and their effects on PA and motivation, assess the accuracy of a novel WFT device in the free-living environment, investigate the impact of WFT use on motivation and PA in WFT users and former users, and determine the effect of WFTs, MI, and the two together on PA and motivation. To address these objectives, I proposed the following specific aims:

Specific Aim 1

To determine the state of the literature as it pertains to the effects of WFTs, MI, and the two combined on motivation for PA, and PA behavior in adults.

Approach

A systematic literature was conducted using Preferred Reporting System for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[15]

Hypothesis

Both MI and WFTs alone will have a small to medium impact on both motivation for PA behavior. Combined, the effect will be larger than either intervention alone.

Specific Aim 2

To determine if a novel WFT device, the STYR Shyft (STYR Labs Inc., Scottsdale, AZ) is a valid and accurate device for use in PA research and PA interventions.

Approach

An accuracy assessment was conducted with participants wearing the STYR Shyft and an ActiGraph (ActiGraph Corp., Pensacola, FL) clinical grade accelerometer, serving as the criterion measure, for seven days. Using guidelines from the Consumer Technology Association, Styr estimated energy expenditure and steps were compared to ActiGraph estimated variables.

Hypothesis

Based on research conducted on a similar device, the STYR Shyft will be accurate (±10% MAPE) in estimating step counts but not in estimating energy expenditure.

Specific Aim 3

To identify and describe the differences between current and former WFT users in PA activity, and motivation for PA.

Approach

A mixed-methods cross-sectional study with a survey and semi-structured interviews was conducted.

Hypothesis

Current WFT users will report higher levels of controlled motivation for PA and higher levels of PA behavior than former users.

Specific Aim 4

To determine if WFT use combined with MI is more effective in increasing PA and shifting PA motivation from more controlled to more autonomous in inactive adults than either intervention alone.

Approach

A randomized controlled trial with four conditions, WFT, MI, WFT and MI combined, and a PA education comparison condition, was conducted with inactive adult participants.

Hypothesis

Participants in the WFT and MI combined condition will have increases in autonomous motivation for PA and in PA behavior. This group will also have higher levels of autonomous motivation and PA behavior when compared to other conditions after 12 weeks.

By studying these aims, we expect to: have a deep understanding of how WFTs, alone and in combination with MI, impact self-determined motivation for PA and PA itself, identify a novel commercial wearable device for use in free-living PA research, understand how motivation and PA differ in current and former WFT users, and how an intervention using both WFTs and MI can increase autonomous motivation and PA in inactive adults. We will not only move the

field of wearable research forward by identifying a novel and accurate wrist-worn wearable, but also by developing a reproducible and effective intervention for PA behavior change.

CHAPTER 2- EFFECTS OF MOTIVATIONAL INTERVIEWING AND WEARABLE FITNESS TRACKERS ON MOTIVATION AND PHYSICAL ACTIVITY: A SYSTEMATIC REVIEW

SUMMARY

Objective: To systematically review the impacts of Wearable Fitness Trackers (WFTs), Motivational Interviewing, and Self Determination Theory (SDT) based interventions on physical activity (PA) and motivation for PA.

Data Source: Manuscripts published between 2008 and 2018 in PubMed, Web of Science, CABAbstracts, and SPORTDiscus databases, were reviewed.

Study Inclusion and Exclusion Criteria: Inclusion criteria were original pilot studies, randomized controlled trials (RCT), cross sectional studies, qualitative assessments, prospective cohort studies, longitudinal observational studies, and pretest posttest designs published in peer reviewed journals.

Data Extraction: Studies were evaluated by two independent researchers for inclusion.

Data Synthesis: Extracted data were synthesized in a tabular format and narrative summary.

Results: Twenty-nine studies met final inclusion criteria, 11 addressed WFT use and PA behavior, 4 investigated WFT use and its association with motivation for PA, and 12 examined

[1] This chapter was accepted for publication in the *American Journal of Health Promotion* and was published online first on July 14, 2020. Details of the publication are listed below:
Effects of Motivational Interviewing and Wearable Fitness Trackers on Motivation and Physical Activity: A Systematic Review.

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SDT and/or MI and their effect on motivation for PA and/or PA behavior. Finally, 2 studies addressed SDT based MI, WFT use, and the combined effect on PA behavior. WFTs use provides a promising combination of interventions to increase PA among sedentary

Conclusions*:* While SDT based interventions and MI positively impact motivation for PA and PA behavior, WFTs revealed mixed results. WFTs prove effective among individuals not currently meeting PA guidelines, but have little impact on other populations. SDT, MI, and

individuals, though research is limited.

Background

Physical Activity and Health

Only a quarter of American adults engage in the recommended 150 minutes of moderate physical activity (PA) that is associated with a reduced risk of chronic diseases such as diabetes, heart disease, and some cancers.[22] In order to address this disparity, the American College of Sports Medicine and the American Medical Association established Exercise is Medicine (EIM), an initiative to improve the promotion of PA in primary healthcare.[20] After an initial phase of raising awareness of the benefits of PA and healthcare integration, EIM entered into its second phase, the EIM Solution.[20] PA behavioral counseling is a cornerstone of the EIM Solution and materials provided by EIM specifically recommend the use of Motivational Interviewing (MI) by health and fitness professionals.[23]

Self-Determination Theory of Motivation

To better understand how MI affects PA behavior, we must first explore how PA behavior can be influenced by motivation. Creators of the Self-Determination Theory (SDT) of motivation, Ryan and Deci,[6] describe motivation as what drives people to act and propose that it lies on a continuum from controlled (external or coerced) to autonomous (internal or volitional).

SDT's foundation is that humans have three basic psychological needs: autonomy, competence, and relatedness. The fulfillment of these needs supports the development of more autonomous motivation for a given behavior. Autonomy is the need to self-regulate one's own behaviors and experiences.[6] Competence, which is dependent on context, is the need to master a behavior.[6] Individuals feel a sense of relatedness, the third psychological need, when they are socially connected and feel cared for by others.[6]

On one end of the motivation continuum lies intrinsic motivation, the most autonomous form, with behaviors grounded in interest, enjoyment, and a sense of inherent satisfaction.[7] In contrast to intrinsic motivation, behaviors that are extrinsically motivated vary greatly in the mechanisms that controls them. The most extreme form of extrinsic motivation is external regulation, in which behaviors stem from a desire to be compliant, to conform, or to receive external rewards or avoid external punishments.[7] In between external regulation and intrinsic motivation lie three more forms of extrinsic motivation, increasing in their level of autonomous control. They are: introjected regulation, identified regulation, and integrated regulation.[7] Finally, amotivation describes a state in which the individual is non-autonomous and lacks drive for the behavior.[7]

In reference to PA, SDT acknowledges that people can move through the motivation continuum towards intrinsic motivation if their psychological needs fulfillment is supported with education, encouragement, and intervention.[24] This is important because Ryan and Deci[7] point out, more autonomous forms of motivation may lead to more persistent engagement in moderate to vigorous PA. A review by Teixeira and colleagues[8] supports this statement, indicating that autonomous motivation is associated with PA engagement in adults. Specifically, identified

regulation predicts initial adoption and short-term engagement whereas intrinsic motivation predicts long-term participation.[8]

Motivational Interviewing

MI is a person-centered form of engagement that employs a set of specific techniques to encourage the assessment of one's own position on the motivation continuum. While not intentionally designed based on SDT, a number of MI techniques align with the tenants of SDT. For example, MI emphasizes empathetic listening by the practitioner. The client or patient must feel accepted in order to enact behavior change, which reflects SDT's psychological need of relatedness.[21] The psychological need of autonomy is supported by the central belief of MI that practitioners should explore and understand the patient's motivations for and ambivalence toward change.[21] Furthermore, empowering the patient to make decisions and take action for change reflects the SDT construct of competence by improving self-confidence in the capacity for change.

Wearable Fitness Trackers

Among recommendations like MI, the EIM Solution also recommends the use of active health technology such as pedometers and wearable fitness trackers (WFTs) , to provide patients with real-time PA feedback and cues to move throughout the day.[20] Wearable fitness trackers (WFT) are small, relatively low-cost, and user-friendly devices that been developed to support sedentary individuals in increasing their PA engagement.[25] WFTs are exceedingly popular with over 120 million units sold worldwide in 2018, a number that is expected to reach almost 200 million by 2022.[4] Although WFTs have saturated the health and fitness industry, it is unknown whether the technology impacts PA and, if so, what mechanism influences PA participation.[14] Schaben and Furness[9] speculate that WFT features can impact motivation as framed by SDT. Receiving immediate feedback on progress toward a goal (i.e. completing 10,000 steps per day)

may improve individual's competence for the activity.[9] Self-monitoring of a behavior, such as walking, can enhance an individual's autonomy for goal-setting.[9] WFTs also allow individuals to choose the type of PA that they wish to engage in, rather than assigning them a modality, further enhancing their autonomy for PA.[9] A study by Karapanos and colleagues[26] indicates that relatedness is supported by WFTs by virtue of both online social interactions through the associated mobile applications and real world relationships. These researchers report that WFT users feel increased relatedness when their friends or family members also have WFTs and support each other to reach their PA goals.[26]

As the EIM Solution continues to encourage the development and establishment of integrated PA initiatives in healthcare and community settings, EIM researchers[20] acknowledge the need for investigation of the effectiveness, feasibility, and sustainability of program components. Therefore, the purpose of this review is to collect and appraise the literature on MI, WFT use, or a combination, and their impact on motivation for PA through the SDT lens and PA behavior.

Methods

Data Sources

Figure 1 shows the search strategy for this review. An electronic literature search was conducted in the PubMed, Web of Science, CABAbstracts, and SPORTDiscus databases. Keywords included motivation, wearable fitness trackers, wearable tracker, fitness tracker, pedometer, Fitbit, Apple Watch, self-determination theory, motivational interviewing, extrinsic motivation, intrinsic motivation, autonomous motivation, controlled motivation, physical activity, and exercise.

Inclusion Criteria

Inclusion criteria were original pilot studies, randomized controlled trials (RCT), cross sectional studies, qualitative assessments, prospective cohort studies, longitudinal observational studies, and pretest posttest designs published in peer reviewed journals. Studies could be conducted in either a controlled setting or in the free-living environment and could include subjects of any age, with or without disability or disease, and be either sedentary or active. Included studies had independent variables of WFT use, interventions using components of SDT and/or MI, or a combination of the three. Dependent variables were PA, motivation for PA, sedentary time, cardiorespiratory fitness or a combination of any of these.

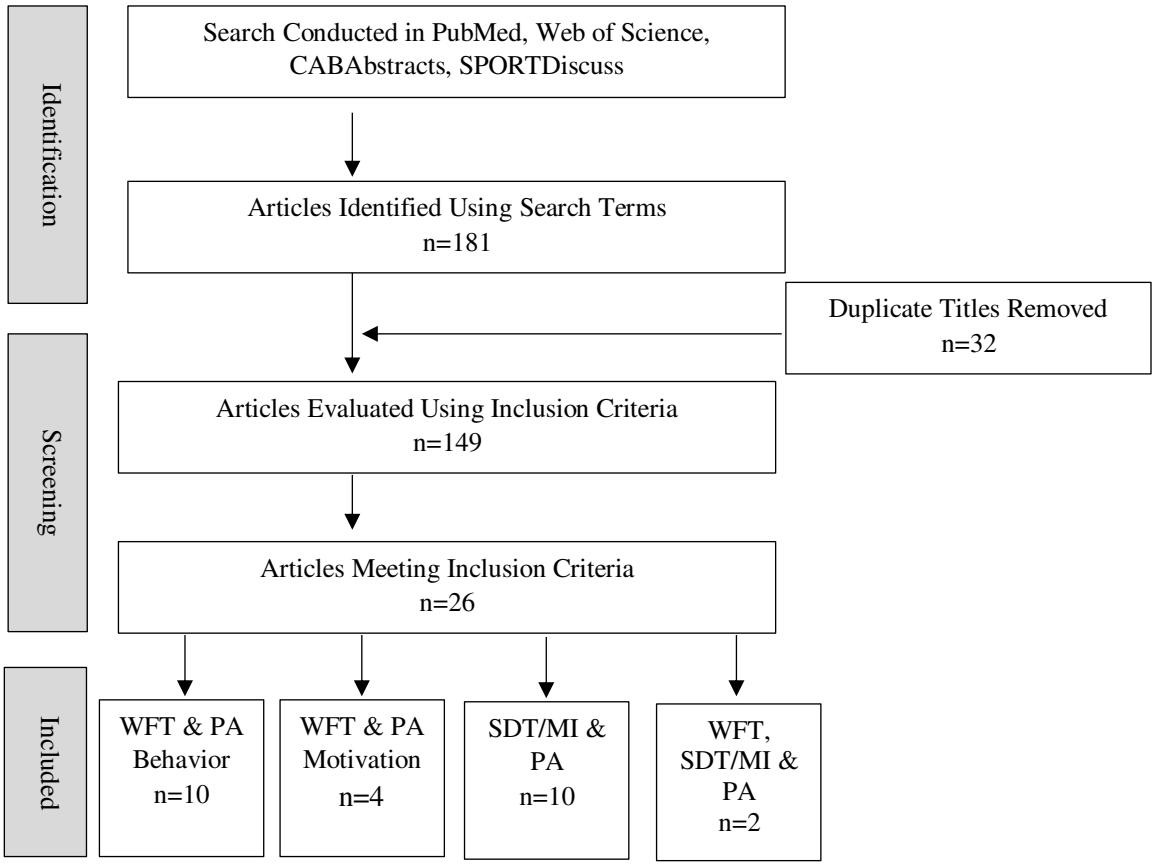

Figure 1. Selection of Included Articles

Exclusion Criteria

We excluded review papers, methods descriptions, rationale papers, qualitative assessments of intervention participant experience, and validation studies of WFTs.

Data Extraction

Only studies written in English were included. A date filter of January 1, 2008 (as Fitbit, one of the first WFTs, became available in 2008[13]) to November 20, 2018. No further limits were applied. Reference lists were searched to discover additional studies. After duplicate titles were removed, two independent researchers evaluated the remaining studies.

Results

Study Selection

The search identified 181 potential publication titles. Thirty-two titles were duplicates and the remaining 149 studies were evaluated. Twenty-six studies met the inclusion criteria. (See Figure 1). Table 1 shows study and participant characteristics. Of those 26 studies (see Table 2), 10 addressed WFT use and PA behavior, 4 studies investigated WFT use and its association with motivation for PA, and 10 studies examined SDT and/or MI and their effect on or association with motivation for PA and/or PA behavior. Two studies addressed SDT based MI, WFT use, and the combined effect on PA behavior.

Research Summaries

WFTs and PA Behavior

Effects of WFT use on PA behavior are mixed among adolescents, college-aged young adults, adults, and older adults. In one sample of adolescents, WFT use was associated with increased fitness and weight loss.[27] Studies of college-aged students, however, revealed mixed results. In one sample of college-aged adults, WFTs were associated with increased PA[28] whereas in two other samples, they were associated with small, non-significant increases in step

count,[9] and increases in sedentary time.[29] In adults, however, WFTs were associated with increases in both self-reported PA[30,31] and objectively measured PA.[32-36] Two studies showed PA increased only in individuals not already meeting PA recommendations,[30,34] indicating perhaps that WFTs are most effective in sedentary or under active adults.

Table 1. Study and Participant Characteristics

	Number of Studies	Number of participants Mean(SD), Range	Number of Males	Number of Females	Age (in years)	Countries Represented
WFT Use and PA Behavior	10	124.67±218.01 (range: 18 to 800)	51.18±106.64 (range: 0 to 370)	78.27±120.44 (range: 10 to 430	38.60±18.16 (range: 17 to 69 years in studies reporting age)	United States, Germany, Singapore, United Kingdom
WFT Use and Motivation for PA	4	72.33±54.06 (range: 10 to 107)	40.67±34.21 (range: 2 to 67)	31.33±20.60 (range: 8 to 79)	33.30±24.70 (range: 13.5 to 67)	United Kingdom, United States
SDT/MI and PA Motivation and Behavior	10	338.55±594.09 (range: 35 to 2058)	96.36±186.60 (range: 0 to 638)	242.18±422.59 (range: 22 to 1430)	41.21±18.10 (range: 13 to 59) years old	Iran, France, Norway, Australia, United States, Netherlands, Canada, Greece
WFT Use, SDT/MI and PA Motivation and Behavior	2	19.33±17.90 (range: 9 to 40).	40	9	36.00±18 (range: 15 to 47)	United States

Note- WFT: Wearable fitness tracker; PA; physical activity; SDT: Self-Determination Theory; MI: motivational interviewing

Table 2. Included Studies by Topic

WFT Use and PA Behavior								
Author(s) & year	Sample	Study design	SDT	MI	Wearable fitness trackers	Length of Intervention	Outcome Variable of Interest	Main Findings
Schrager, et al. (2017)	30 Emergency Medicine Residents 14 males, 16 females Mean age: 28 years	Pre-Post Cohort	No	No	Yes	27 Weeks	Self-reported PA	Significant increase in self-reported PA in individuals not meeting CDC guidelines at baseline.
Rote, (2017)	56 College Aged Students 30 males, 26 females Mean age: 20 years	Cluster RCT	No	No	Yes	10 Weeks	Daily steps measured by WFT	Significant increase in daily steps in intervention group when compared to controls.
Steinert, et al. (2018)	20 Older Adults 10 males, 10 females Mean age: 69 years	Pilot Study	No	No	Yes	4 Weeks	Self-reported PA	Significant increase in self-reported PA post-intervention.
Cadmus-Bertram, et al. (2015)	51 Sedentary Women 0 males, 51 females Mean age: 60 years	RCT	No	No	Yes	4 Weeks	Objectively measured PA	Significant increase in objectively measured MVPA, and steps compared to baseline in intervention group. Non-significant increases in comparison group.
DiFrancisco-Donoghue, et al. (2018)	113 Medical Students	RCT	No	No	Yes	40.5 Weeks	Daily steps	Weekly behavioral challenges

	53 males, 60 females Age range 17-50 years (mean not reported)						measured by WFT	delivered via email combined with WFT increased daily steps more than WFT alone.
Finkelstein, et al. (2016)	800 employees in 13 organizations 370 males, 430 females Mean age: 35.5 years	Cluster RCT	No	No	Yes	27 Weeks	Objectively measured PA	Significant increase in objectively measured MVPA in WFT plus cash incentive group at 6 months.
Kim, et al. (2018)	187 College Aged Students 71 males, 116 females Mean age: 20.21 years	Cluster RCT	No	No	Yes	15 Weeks	Objectively measured PA Objectively measured sedentary time	No effect of WFT on objectively measured PA compared to comparison group. WFT use associated with an increased in objectively measured sedentary time.
Gordon & Bloxam (2017)	18 Adults with Back Pain Sex not reported Mean age: 53 years	RCT	No	No	Yes	6 Weeks	Daily Step Count	Significant increase from baseline in daily steps for WFT group. No difference from comparison group who wore a basic pedometer. Significant increase in WFT group

							Aerobic Fitness	above baseline and when compared to comparison group.
Wang, et al. (2015)	20 Overweight and Obese Adults 6 males, 61 females Mean age: 48 years	RCT	No	No	Yes	6 Weeks	Objectively measured PA	Significant increase in MVPA at six weeks. Comparison group used a WFT and received text messaged prompts for PA. No differences were seen between groups.
Schaben & Furness (2018)	134 College Students 43 males, 91 females Ages not reported	Pre-Post Cohort	No	No	Yes	12 Weeks	Daily Step Count	Non-significant increase in daily steps post-intervention
WFT Use and Motivation for PA								
Author(s) & year	Sample	Study design	SDT	MI	Wearable fitness trackers	Length of Intervention	Outcome Variable of Interest	Main Findings
Wilson, et al. (2017)	20 Overweight Adolescents 8 males, 12 females Mean age: 16.8 years	Pre-Post Cohort	No	No	Yes	12 Weeks	Fitness Self-Determination for PA	Significant increase post-program in muscular endurance and strength Significant increase post-program in self-determination for PA.
Kerner & Goodyear (2017)	100 Adolescents	Mixed Methods Pre-Post Cohort	No	No	Yes	8 Weeks	SDT Constructs in Relation to PA	Significant decrease in: Competence, relatedness, autonomy, and

	53 males, 47 females Mean age: 13.5 years							autonomous motivation for PA. Significant increase in: Controlled motivation and amotivation for PA.
Gualteri, et al. (2016)	10 Adults with Chronic Medical Conditions 2 males, 8 females Mean age: 61years	Pre-Post Cohort Qualitative Assessment	No	No	Yes	12 Weeks	Motivation for PA	Feedback about PA from WFT was associated with an increase in motivation for PA.
Lystrup, et al. (2016)	107 Military Medical Students 67 males, 9 females Mean age: 25.4 years	RCT	No	No	Yes	58.5 Weeks	Motivation for PA	Increase in subjective motivation for PA in WFT group compared to comparison group.
SDT Based MI, Motivation for PA, and PA Behavior								
Author(s) & year	Sample	Study design	SDT	MI	Wearable fitness trackers	Length of Intervention	Outcome Variable of Interest	Main Findings
Mahmoobad, et al. (2017)	70 Sedentary Women of Reproductive Age 0 males, 70 females Age range: 15-49 (mean not reported)	RCT	Yes	Yes	No	4 SDT-based MI sessions or 4 educational sessions	SDT Constructs in Relation to PA	Significant increase in: Intrinsic motivation for PA, autonomy, identified regulation, introjected regulation, competence, and relatedness. Significant decrease in:

							Self-reported PA	amotivation for PA. Significant increase in self-reported PA. Significant decrease in self-reported sedentary time.
Gourlan, et al. (2013)	54 Overweight and Obese Adolescents 32 males, 22 females Mean age: 13 years	RCT	Yes	Yes	No	2 Standard Weight Loss Sessions or 2 Standard Weight Loss Sessions and 6 MI Sessions	SDT Constructs in Relation to PA Self-reported PA	Significant increase in: Integrated regulation, identified regulation, intrinsic motivation, and autonomy support. Significant increase in self-reported PA.
Pedersen, et al. (2018)	202 Adults in a Worksite Wellness Program 154 males, 48 females Mean age: 42.5 years	Cluster RCT	Yes	Yes	No	16 Weeks	SDT Constructs in Relation to PA	Significant increase in: intrinsic motivation, perceived competence, and need support.
Riiser, et al. (2014)	120 Overweight and Obese Adolescents 47 males, 73 females Mean age: 13.7 years	CT	Yes	Yes	No	12 Weeks	SDT Constructs in Relation to PA Self-reported PA	No significant intervention effect. No significant intervention effect.

Worawong, et al. (2018)	59 Adults 12 males, 47 females Mean age: 47.6 years	Pre-Post Cohort	Yes	No	No	6 Weeks	Self-reported PA	Significant increase in self-reported PA.
Friederichs, et al. (2016)	2068 Adults 638 males, 1430 females Mean age: 45.14 years.	RCT	Yes	Yes	No	14 Weeks	SDT Constructs in Relation to PA Self-reported PA	Significant increases in: autonomy, competence, and relatedness. Significant increase in self-reported PA.
Friederichs, et al. (2015)	2068 Adults 638 males, 1430 females Mean age: 45.14 years.	RCT	Yes	Yes	No	14 Weeks	Long-term (12 months post-intervention) self-reported PA	Non-statistically significant increase in weekly minutes of MVPA over controls.
Hardcastle, et al. (2012)	207 Adults 72 males, 135 females 70% over 50 years of age (mean not reported)	Pre-Post Cohort	Yes	Yes	No	27 Weeks	SDT Constructs in Relation to PA Self-reported PA	Significant decrease in extrinsic motivation for frequent attenders vs. infrequent attenders. Significant increase in self-reported PA for frequent attenders vs. infrequent attenders.
Rutten, et al. (2014)	298 Overweight and Obese Adults 105 males,	Prospective cohort study	Yes	Yes	No	18 Weeks	SDT Constructs in Relation to PA	Significant increases in: intrinsic motivation and integrated regulation.

	193 females Mean age: 55.5 years							Significant decrease in: external regulation and amotivation.
Moustaka, et al. (2012)	35 Adult Women 0 males, 35 females Mean age: 44.26 years	RCT	Yes	No	No	8 Weeks	SDT Constructs in Relation to PA Self-reported PA	Significant increase in: perceived autonomy support, identified regulation, and intrinsic motivation. Significant increase in self-reported PA.
WFT Use, SDT Based MI, Motivation for PA, and PA Behavior								
Author(s) & year	Sample	Study design	SDT	MI	Wearable fitness trackers	Length of Intervention	Outcome Variable of Interest	Main Findings
Dean, et al. (2018)	40 African American Men 40 males, 0 females Mean age: 47 years	Pre-Post Cohort	Yes	Yes	Yes	10 Weeks	Self-reported PA	Significant increase in self-reported PA.
Bianchi-Hayes, et al. (2018)	9 Dyads of and Overweight Adolescents and a Parent Adolescents: 5 males, 0 females Parents: 0 males, 9 females Mean ages:	Pre-Post Cohort	No	Yes	Yes	10 Weeks	Success in meeting step goal. Success in meeting active minutes goal.	Participants met personalized step goal 30% of the time. Participants met active minutes goal 50-89% of the time.

	Adolescents- 15 years Parents-47 years							

Note. WFT: Wearable fitness tracker; PA; physical activity; SDT: Self-Determination Theory; MI: motivational interviewing.

Wearable Fitness Trackers, Motivation, and Physical Activity

Four studies assessed WFT use and motivation for PA: two in adolescents and two in adults. It is important to note, however, that only the two studies in adolescents used the SDT framework to assess motivation.[36,37] In one sample of overweight adolescents, WFT use was associated with increased self-determined motivation for PA, as well as increased muscular endurance and strength.[27] Conversely, in another sample, adolescents who wore a Fitbit Charge for eight weeks reported decreased competence, autonomy, relatedness, and autonomous motivation and increased amotivation for PA.[37] Furthermore, while the social aspect of the Fitbit mobile application (adding friends and participating in competitions) increased their sense of relatedness, competing in and of itself increased forms of controlled motivation.[37] In contrast, in a sample of adults, the addition of a WFT positively influenced motivation for PA.[38] Self-efficacy for exercise was also improved and participants contributed this to the sense of accountability that the participants felt while wearing the tracker. A fourth study by Lystrup and colleagues[39] showed that Fitbit users reported an increase in motivation for PA over 13 months, compared to a control group. In summary, these studies suggest that WFT use may be beneficial in improving motivation for PA in adults, in older adults, and in overweight adolescents, although more research is required to further explore this theme.

Motivational Interviewing, Motivation, and Physical Activity

This review indicates that MI is effective in improving PA behavior in a range of age groups. In six of the included studies, increases in objectively measured or self-reported PA were seen.[40-45] Other health related improvements included increases in cardiorespiratory fitness,[40,46,47] decreases in BMI,[40,41,47] and decreases in systolic blood pressure and non-HDL cholesterol.[46]

Our review indicated that MI is a powerful intervention to improve autonomous motivation for PA,[13,40,46,48] and to reduce amotivation for PA.[40,41,48] Furthermore, these studies indicate that the delivery of the intervention can vary from telephone,[41] to internet,[44,47,49,50] and to one-on-one in-person coaching[45,48] and can still be effective in impacting motivation and PA, regardless of the delivery method.

Wearable Fitness Tracker, Motivational Interviewing, and Physical Activity

Two pilot studies have assessed the impact of combining a WFT with SDT based MI or MI alone on PA behavior. In one study, nine parent-child dyads, wore WFTs and received telephone delivered MI.[51] On 35% of the days the trackers were worn, the adolescents met their personalized daily step goal; whereas on 39% of the days the tracker was worn, parents met their personalized step goal. These researchers also found that parent and child step counts were correlated.[51]

In another pilot study, Dean and colleagues[52] evaluated the effects of a PA program for African American men that incorporated SDT based MI delivered in groups and WFTs. They saw a significant increase in total weekly minutes of moderate and vigorous PA, improvements in body weight, body fat percentage, and HDL cholesterol levels after the eight-week intervention. Unfortunately, neither of these studies[51,52] evaluated self-determination motivation constructs.

Discussion

In summary, this review assessed 29 original research studies with MI, WFTs, or a combination of the two and their impact on motivation for PA and PA behavior across a range of ages. WFTs are associated with increases in PA in some age groups, whereas in others they were limited in their effectiveness. WFTs also seem to be an effective means to support more autonomous motivation for PA in adults and overweight adolescents. Most WFTs provide instantaneous feedback on progress toward PA goals and this performance feedback can enhance or thwart the psychological need of competence, depending on whether it is positive or negative.[53] In Kerner and Goodyear's study[37] for example, participants reported that they were often unable to complete the 10,000 step goal set by their WFTs. They consistently felt as though they were failing, negatively impacting their sense of competence.[37] People experiencing consistent failure may also feel guilt or shame, the avoidance of which is associated with introjected regulation.[8] While introjected regulation can be linked to improvements in PA, Teixeira and colleagues[8] determined that it is not related to long-term PA persistence. Along these lines, Segar[54] suggests that WFTs are actually incapable of motivating individuals to engage in PA behavior in the long-term. She recommends combining tracker usage with what she terms, "motivation generators."[54] These motivation generators are grounded in SDT and focus on users finding their primary purpose for becoming physically active.[54] They also should find the mode of PA that feels best to them, which can be challenging as many WFTs cannot effectively track PA like bicycling, as the device is typically affixed to the wrist or waist.[54]

In contrast, Gualtieri and colleagues[38] found that WFT feedback enhanced competence by providing participants with instant gratification and satisfaction of reaching or exceeding goals. In this study, participants were able to use the default 10,000 step goal, or have a personalized

goal set for them based on their physical limitations.[38] Schaben and colleagues[9] suggest that WFTs allow users to set goals (i.e. step goals, calorie burn goals) that are individually tailored, potentially enhancing user competence. Similarly, Segar[54] encourages a learning mindset in which the user moves away from rigid PA goals, such 10,000 steps each day, and flexes goals when other life priorities arise.[54] One such project is being undertaken by Centi and colleagues[55] who have built an algorithm that allows a wearable fitness user to set a personalized step goal based on answers to a set of specific questions regarding goals and behaviors. However, the algorithm has yet to be tested.

In this review, MI was effective in increasing autonomous motivation for PA and reducing amotivation for PA in a number of different populations. It was also associated with increases in both self-reported and objectively measured PA. According to Resnicow and McMaster,[56] people who begin behavior counseling often have initial high levels of amotivation, introjected regulation, or external regulation in which they seek to avoid external punishments or earn internal rewards. The goal of the practitioner is to support the client in the movement toward more autonomous forms of motivation using the MI competencies.[56] These competencies include ensuring that the motivation to change is generated by the client, enhancing autonomy, an empathic and non-judgmental demeanor of the practitioner, enhancing relatedness, and reflections on prior success, improving competence.[56] These competencies were not assessed in studies included in this review, but we speculate that if MI was facilitated in its truest form, movement along the motivation continuum for PA is a reasonable result.

Two studies[51,52] found that combining SDT based MI interventions with WFT use significantly improved self-reported PA, body weight, and HDL cholesterol in African American men[52] and increased the likelihood of meeting daily step goals in adolescent-parent dyads.[51]

According to a review by Sullivan and Lachman,[14] most successful PA interventions incorporate more than one behavior change technique, which may explain some of the success of the studies by Bianchi-Hayes and colleagues[51] and Dean and colleagues.[52] Furthermore, These two studies included interventions delivered to dyads[51] and to a group.[52] While not directly measured in either of these studies, we speculate that the psychological need of relatedness was supported by the group nature of the interventions, thus resulting in PA and health improvements. Combined with the MI competencies and feedback provided by the WFT, interventions like these are promising to improve the psychological needs of autonomy, relatedness, and competence and facilitate movement toward more autonomous motivation for PA.

Limitations

This study is not without at least one limitation. The literature search was not exhaustive and only included four literature databases. It is likely that studies in SDT, MI, and WFT use and their impacts on PA behavior and motivation may not be included.

Conclusion and Future Directions

Researchers, like those involved in the EIM Solution[20] encourage the testing and evaluation of interventions utilizing both WFTs and MI. Given the outcome of this review, the combination is a promising method to improve the overall health of both adolescents and adults.

Researchers and clinicians alike would benefit from taking the advice of Segar[54] and develop PA behavior change interventions that incorporate the goal setting, feedback, and social connectedness allotted by a WFT with the intention to shift motivation from controlled (or amotivation) to more autonomous form as seen with MI. These interventions can be grounded in human interaction, such as in-person group or one-on-one coaching. They might also be built into the WFT technology itself, relying on algorithms. The combination of these strategies seems

promising to improve the state of inactivity and associated health risks, supporting the goals of comprehensive health programs like EIM.

CHAPTER 3- VALIDATION OF THE STYR SHYFT WEARABLE FITNESS TRACKER AGAINST ACTIGRAPH ASSESSED STEPS AND EXERGY EXPENDITURE IN THE FREE-LIVING ENVIRONMENT

Background

Over 77.85 million wearable fitness tracker (WFT) devices were sold between January and August 2019[4] and while they are popular, their utility lies in the accuracy of the measurements. If, for example, individuals are seeking to utilize WFTs for self-monitoring of physical activity (PA) behavior, their accuracy should be tested in the laboratory, but more importantly, also in the free-living environment.[57] Clinical grade accelerometers have undergone extensive testing in both realms. The ActiGraph (ActiGraph Corp., Pensacola, FL), a clinical grade accelerometer, for example, has been validated in the free-living environment to measure activity counts in three orthogonal planes (vertical, anterior-posterior, and mediolateral).[58] The Actigraph is also the most commonly used device for the objective measurement of physical activity in free-living studies.[58,59] Unfortunately, clinical grade accelerometers, such as the ActiGraph can be prohibitively expensive for consumers, or even for some researchers.[60] They also can be difficult to use, often requiring special training and software.[61,62]

Consumer grade wearable fitness trackers (WFTs) , on the other hand, are typically low-cost and provide the user with data such as physical activity time, number of steps, energy expenditure in the form of kcals burned, and more.[25] One such device, the STYR Shyft (SS) (STYR Labs Inc., Scottsdale, AZ) is a small, wrist-worn or waist-worn WFT that, like the Fitbit Flex, tracks daily steps and energy expenditure. The SS also tracks distance traveled and activity time. According to STYR, the device also has a thirty-day battery life. The device does not track

heart rate or have a GPS as other popular WFTs do.[63] The SS syncs to a free mobile application where users can see their progress toward daily personalized step, kcal, distance traveled, and active minute goals. According to materials provided by STYR,[16] the SS contains a tri-axial accelerometer sensor. While the description of the technology is limited, we assume that the sensor is similar to that which Fitbit uses in its devices. According to a review by Feehan and colleagues,[64] Fitbit devices contain a "microelectric triaxial accelerometer to capture body motion in 3-dimensional space" (p. 2). Fitbit data are then analyzed using proprietary algorithms that then provide the user with estimates of steps taken, energy expenditure in kilocalories, exercise intensity, and sleep, for example.[64] Again, while the description of the SS technology is limited, we assume it processes data similarly to the Fitbit devices.

While WFTs were initially developed for use in the free-living environment to influence physical activity behavior, they are increasingly popular for use in research settings.[64] Some WFTs, like Fitbit devices have been tested in both the laboratory and free-living environments to assess their accuracy in comparison to the gold standard measures, such as the ActiGraph. To our knowledge, however, no study has used the SS in a research study nor has any study examined the accuracy of the SS in assessing step count or EE in the free-living environment. Therefore, the purpose of this study was to compare the EE and step count estimated by the SS compared to two waist-worn ActiGraphs (ACT) in the free-living environment for its potential use in research.

Methods

Participant Recruitment and Health Screening

All potential participants were recruited via flyers, emails, and announcements in undergraduate and graduate level classes at Colorado State University. To be included in the

study, researchers required that participants be between 18 and 30 years old, and agree to wear three wearable devices during day to day activity for at least forty-eight hours, only removing them for showering, bathing, or swimming. All procedures were approved by the Colorado State University Institutional Review Board (protocol 19-9238H).

Protocol

This study consisted of two laboratory visits. The participant arrived at the Human Performance Clinical Research Laboratory at Colorado State University and completed the informed consent process with a research team member. Researchers measured the participant's stride length in meters. The participant then had SS placed on one wrist and two ACTs placed on each hip. The placement of the Shyft (right wrist versus left wrist) was randomized among participants. The participant's stride length, height, weight, age, and sex were then entered into the corresponding mobile application on an iPhone 6, running iOS 11 and into the ActiLife Software (ActiGraph Corp., Pensacola, FL). The participant was instructed to not remove the devices except to shower, bathe, swim, or otherwise be immersed in water. The participant was also asked to record the date and time the devices were removed and the date and time they were put back on in a provided log. Researchers instructed the participant to do normal daily activities while wearing all three devices, including sleep. Participants returned to the lab after wearing the three devices for forty-eight consecutive hours and researchers then synced the Shyft with the mobile application, removed the devices from the participant, and the participant was then free to leave the lab.

ActiGraph Physical Activity Monitor

The ActiGraph wGT3X-BT (ACT) was used in this study to assess the participant's steps and EE by measuring all three axes of movement simultaneously. The simultaneous

measurement is done with a sensitivity of 3 mg/Least Significant Bit and a dynamic range of +/- 6 G. This output is then digitalized and filtered to include a range of 0.25-2.5 hertz to limit the range to that of human movement (ActiGraph, 2019). Monitors were initialized prior to the arrival of the participant and the time the devices were placed on the participant was recorded.

Data Preparation and Analysis

An a priori power analysis was conducted to determine the sample size of this study using PASS Power Analysis Software (Kaysville, UT). Twenty (20) participants were required for two one-sided equivalence tests (TOST). A sample size of 20 achieved 95% power at a 5.0% significance level when the actual mean of paired differences in terms of step count is 150, the estimated standard deviation of paired differences is 100, and the equivalence limits are -300 and 300. Similarly, a sample size of 20 achieved 95% power at a 5% significance level when the actual mean of paired differences in terms of EE is 10 kcals, the estimated standard deviation of paired differences is 4kcals, and the equivalence limits are -50 and 50 kcals. The values used for power analysis were estimated based on our previous device accuracy studies.[65,66]

Data from the ACTs were downloaded and processed using ActiLife Software (Version 6.13.3). Energy expenditure was calculated according to the Freedson VM3 Combination algorithm.[58] Metabolic equivalents (METs) and determination of the intensity of physical activity were calculated using the Freedson Adult equation.[67] Step counts were downloaded directly from the devices. After syncing the SS to the mobile application, researchers recorded daily step count and EE values into Microsoft Excel.

We calculated means and standard deviations (SD) for participant height, BMI, and age. We also calculated means and SD for steps per day and EE per day as estimated by each ActiGraph and by the SS. We then calculated the mean differences between the ACT and SS

assessed steps and EE. To assess equivalence between the ACT calculated EE and step counts and the corresponding SS values, two one-sided tests (TOST) procedure was performed based on recommendations from field experts.[68] We deemed the acceptable upper and lower equivalence bounds as the mean value of the criterion measure ± 10%, respectively, based on recommendations from the Consumer Technology Association regarding wearable fitness tracker accuracy.[17] Mean absolute percent error (MAPE) was calculated for step counts and EE from each ACT compared to the SS values. Cohen's d effect sizes were calculated to quantify the differences between the SS steps and EE and the ACT steps and EE values for each day.

Lin's concordance correlation coefficients (CCC) were used to describe the strength of the relationship of ACT measured steps and EE with those of the SS per day. Almost perfect agreement between two continuous variables has a CCC of ≥ 0.99, substantial agreement has CCCs of between 0.95 and 0.99, moderate agreement has CCCs of between 0.90 and 0.95, and poor agreement has a CCC of ≤ 0.90.[69] Statistical significance was set $p \leq .05$. R version 3.4.1 statistical software[70] was used for all analyses.

Results

Twenty-eight young adults (14 females; age: 22.61±3.12 years; BMI: 22.96±1.98; height: 67.5±3.79 inches) participated in the study. After data collection was complete, four participants' data were removed after researchers identified step counts lower than ten steps per day on at least one day as measured by the SS but had ACT step counts were well over 5000 steps on the same day, indicating SS device malfunction. Therefore, the final sample size was n=24 (12 females; age: 22.58±3.27 years; BMI: 23.08±2.05; height: 67.75±3.86 inches). The SS values for estimated steps were not equivalent to either ACT for any day, nor for the total number of steps across three days. The SS consistently overestimated steps. The mean difference in daily steps

ranged from -2290.25 (2721.10) and -2347.25 (2660.50) for the SS compared to the dominant and non-dominant hip ACT, respectively for males on day three to -6237.17 (4540.13) and -6248.67 (4796.22) for the SS compared, again, to the dominant and non-dominant hip ACT, respectively for males on day two (Table 3). Despite removing four outliers, MAPEs were greater than 100% for SS assessed steps when compared to both the dominant and non-dominant ACTs for the whole sample, for men and for women on day 3, as well as for total steps across the three days.

As with the step data, the SS estimated EE was not equivalent to the dominant hip or non-dominant hip ACT estimated values for any day, nor for the total EE across three days. MAPEs were much lower than for step counts, ranging from 23.53% and 23.35% for the males on day 1 compared to the dominant and non-dominant ACTs, respectively to 174.48% and 171.20% for females on day 3 compared to the dominant and non-dominant ACTs, respectively (Table 4). While the SS overestimated steps, it consistently underestimated EE when compared to the ACT values.

Table 3. Mean Steps per Day Assessed by Dominant and Non-Dominant Hip ActiGraphs vs. STYR Shyft, Mean Differences, STYR Shyft Mean Absolute Percent Error, and Results of Lin's CCC and Equivalence Tests

	Steps			STYR vs Dominant ActiGraph					STYR vs. Non-Dominant ActiGraph				
	DH ACT Mean (sd)	NDH ACT Mean (sd)	STYR Mean (sd)	Mean Difference (sd)	MAPE	Lin's CCC	Equiv	Cohen's D	Mean Difference (sd)	MAPE	Lin's CCC	Equiv	Cohen's D
Day 1	7132.48 (3749.08)	7084.04 (3529.72)	11990.00 (5018.37)	-4653.88 (2920.12)	83.02%	0.50	No	1.04	-4708.00 (2920.70)	84.98%	0.50	No	1.06
Males (n=12)	8276.50 (4415.61)	8227.42 (4383.79)	13454.83 (5165.95)	-5178.33 (2650.07)	83.52%	0.52	No	1.08	-5227.42 (2630.90)	84.29%	0.51	No	1.09
Females (n=12)	5800.00 (2390.37)	5740.83 (2397.33)	9929.42 (4621.10)	-4129.417 (3194.74)	82.41%	0.37	No	1.12	-4188.58 (3213.44)	85.80%	0.36	No	1.14
Day 2	10134.52 (4367.89)	10182.30 (4508.14)	15625.79 (6327.60)	-5355.96 (5882.03)	67.02%	0.27	No	0.99	-5302.00 (5994.63)	69.73%	0.27	No	0.97
Males	9389.08 (3764.59)	9377.58 (3844.87)	15626.25 (5227.20)	-6237.17 (4540.13)	82.07%`	0.25	No	1.37	-6248.67 (4796.22)	88.19%	0.23	No	1.36
Females	11150.58 (4817.79)	11270.00 (4991.47)	15625.33 (7509.55)	-4474.75 (7073.53)	52.24%	0.29	No	0.71	-4355.33 (7083.72)	50.59%	0.31	No	0.68
Day 3	5136.32 (5263.56)	5139.23 (5414.66)	8247.87 (6839.08)	-2924.48 (2868.47)	237.84%	0.80	No	0.49	-2922.26 (2804.24)	286.00%	0.81	No	0.48
Males	3475.58 (3108.07)	3418.58 (3093.58)	5765.83 (4035.55)	-2290.25 (2721.10)	385.55%	0.59	No	0.64	-2347.25 (2660.50)	358.84%	0.59	No	0.65
Females	6505.73 (6674.52)	6572.55 (6900.12)	10043.83 (8554.70)	-3616.36 (2991.27)	207.47%	0.83	No	0.49	-3549.55 (2946.97)	198.60%	0.84	No	0.44
Total	16124.37 (7527.27)	16175.36 (7714.38)	36541.09 (11037.21)	-18843.80 (9417.63)	151.55%	0.23	No	1.79	-18777.25 (9559.60)	152.11%	0.22	No	1.83
Males	13550.88 (6116.96)	13475.26 (6125.36)	34846.92 (10417.23)	-22408.62 (6508.77)	181.59%	0.14	No	2.49	-29954.59 (7437.63)	184.19%	0.14	No	2.50
Females	18739.10 (7925.16)	18942.55 (8180.20)	35511.45 (15233.25)	-23427.57 (11264.94)	106.86%	0.32	No	1.26	-16059.84 (11555.87)	104.96%	0.33	No	1.36

Note: DH= dominant hip, NDH=non-dominant hip, ACT= ActiGraph, SD= standard deviation, MAPE= mean absolute percent error, CCC= concordance correlation coefficient, Equiv= equivalence test

Table 4. Mean Energy Expenditure per Day Estimated by Dominant and Non-Dominant Hip ActiGraphs vs. STYR Shyft, Mean Differences, STYR Shyft Mean Absolute Percent Error, and Results of Lin's CCC and Equivalence Tests

	KCALS			STYR vs. Dominant ActiGraph					STYR vs. Non-Dominant ActiGraph				
	DH ACT Mean(sd)	NDH ACT Mean(sd)	STYR Mean(sd)	Mean Difference (sd)	MAPE	Lin's CCC	Equiv.	Cohen's D	Mean Difference (sd)	MAPE	Lin's CCC	Equiv.	Cohen's D
Day 1	555.31 (263.26)	555.31 (255.39)	408.00 (180.84)	149.66 (139.34)	25.77%	0.67	No	-0.66	148.80 (135.01)	26.13%	0.66	No	-0.67
Males n=12	686.22 (290.96)	679.09 (280.11)	500.08 (170.21)	186.13 (166.19)	23.53%	0.57	No	-1.15	179.01 (152.34)	23.35%	0.59	No	-0.78
Females n=12	407.43 (123.18)	412.84 (126.58)	294.25 (138.61)	113.18 (100.38)	28.46%	0.50	No	-1.02	118.59 (113.65)	29.48%	0.44	No	-0.89
Day 2	765.25 (245.30)	760.16 (236.30)	543.26 (161.80)	205.26 (196.14)	30.19%	0.39	No	-0.97	204.50 (175.22)	30.26 %	0.43	No	-0.98
Males	809.78 (252.20)	794.65 (232.21)	578.42 (143.59)	231.36 (204.53)	28.91%	0.30	No	-1.13	216.24 (183.70)	29.99%	0.32	No	-1.12
Females	722.90 (229.53)	736.51 (239.56)	543.75 (216.85)	179.15 (192.66)	31.71%	0.46	No	-0.80	192.76 (173.64)	30.58%	0.51	No	-0.84
Day 3	353.29 (245.37)	352.48 (256.69)	265.13 (199.22)	62.41 (176.54)	101.63%	0.67	No	-0.28	61.65 (177.01)	99.19%	0.68	No	-0.27
Males	292.02 (195.80)	288.85 (197.41)	219.67 (148.43)	69.18 (149.03)	41.02%	0.58	No	-0.42	72.36 (151.65)	39.19%	0.59	No	-0.40
Females	391.10 (297.31)	392.98 (314.56)	333.92 (225.40)	51.55 (207.41)	174.48%	0.68	No	-0.22	53.44 (210.62)	171.20%	0.69	No	-0.22
Total	1658.50 (427.49)	1650.60 (421.59)	1216.39 (323.40)	403.39 (339.65)	27.22%	0.39	No	-1.05	401.05 (311.95)	26.81%	0.41	No	-1.07
Males	1788.02 (480.69)	1762.59 (477.34)	1298.17 (316.60)	489.85 (302.46)	25.83%	0.40	No	-1.20	464.42 (287.48)	24.90%	0.44	No	-1.15
Females	1488.84 (325.29)	1509.59 (321.38)	1171.92 (343.07)	316.92 (365.26)	30.32%	0.27	No	-0.94	337.67 (334.75)	29.10%	0.32	No	-1.02

Note: DH= dominant hip, NDH= non-dominant hip, SD= standard deviation, MAPE= mean absolute percent error, CCC= concordance correlation coefficient, Equiv= equivalence test

Discussion

To our knowledge, this is the first study to assess the step count and EE accuracy of the STYR Shyft wearable fitness tracker in comparison to the ActiGraph clinical grade accelerometer in the free-living environment. The results indicate that neither SS step estimates nor SS EE estimates were accurate when compared the ACT estimated values. The SS grossly overestimated steps with MAPEs well over 100% in some cases, and underestimated EE, although the MAPEs were much lower, ranging from approximately 24% to over 170%, although most MAPE values were on the lower end of that spectrum.

According to the Consumer Technological Association (CTA)[17], a WFT is considered accurate when it's estimated step count values are within 10% MAPE when compared to manually counted steps. While the CTA report deems manually counted steps to be the criterion measure, ACT accelerometry is also considered a gold standard and has been used in a number of studies[71-76] as a comparison for commercial WFTs in the free-living environment as manually counting steps in this context is not feasible. The SS step counts were well above 10%, and in some cases reached as high as 385.55% when compared to the dominant hip ACT. Clearly, this device cannot be considered accurate for step assessment, according to the requirements set forth by the CTA.

Whereas no other study has assessed the SS for step or EE accuracy, others have assessed the accuracy of Fitbit devices, which we deem similar to the SS. Reid et. al,[57] for example, found that the Fitbit Flex and the Fitbit One are as accurate as the ActiGraph when measuring steps. Dominick et al[73] also examined the agreement between the wrist-worn Fitbit Flex and the waist-worn ActiGraph GT3X in assessing steps per day and these researchers found a strong correlation between the two values (r=.91). Sushames et al[62] also assessed the Fitbit Flex and its

agreement with the ActiGraph GT3X+ in assessing step counts. They found that the Fitbit Flex has significantly lower assessment of steps when compared to the ActiGraph in the free living environment over the course of a day, with an absolute difference of approximately 3000 steps or 47% as a proportion. A review by Feehan and colleagues[64] evaluated twenty different studies that assessed Fitbit accuracy in step count in the free living environment and determined that eleven showed the Fitbit to have ±10% measurement error. Six studies found less than 10% error, whereas three found more than 10% error. Overall, the Fitbit showed a tendency to overestimate steps in the free-living environment.[64]

When comparing Fitbit calculated EE with criterion measures, results have been mixed. In a study comparing the Fitbit (specific model not specified) to whole room calorimetry, the Fitbit was found to have 28% root mean square error for energy expenditure estimations across four hours.[77] Brooke and colleagues[78] evaluated the EE estimation of the Fitbit Charge HR and the Fitbit Flex in the free-living environment using the SenseWear Armband as a criterion measure. The Fitbit Flex had MAPE of 15.5% and the Fitbit Charge HR had MAPE of 16.2%. In a study comparing the Fitbit Flex to the ActiGraph to assess EE in the free-living environment, Sushames and colleagues[62] determined that the Fitbit Flex consistently overestimated activity EE by 50%.

Limitations

This study is not without at least one limitation. Whereas each participant wore the ActiGraphs and the SS for at least 48-hours, some wore the devices during weekend days, others only wore them during weekdays. This inconsistency in wear days should not affect the results to a large degree as each participant served as his or her own control.

Conclusions and Future Directions

In this study, we determined that the SS WFT is grossly inaccurate in assessing daily step count, with MAPE reaching over 300% in some instances. This value far supersedes the guideline set by the CTA, which requires a MAPE of 10% or less to be considered accurate. Similarly, the MAPE for EE as estimated by the SS was also consistently outside of that boundary. Despite the mixed results from studies assessing the accuracy of the Fitbit for estimation of step count and energy expenditure, it is clear that the inaccuracy of the Fitbit does not approach that of the SS. Currently, the Fitbit is widely used in research settings. According to Feehan and colleagues[64], nearly one-hundred clinical trials were registered between 2015 and 2017 with Fitbit measures as outcome variables. Taken with the inaccuracy of the SS, it is our determination that, when possible, the STYR Shyft should not be used in research settings if use of Fitbit devices is an option.

CHAPTER 4- MOTIVATION FOR PHYSICAL ACTIVITY AND PHYSICAL ACTIVITY ENGAGEMENT IN CURRENT AND FORMER WEARABLE FITNESS TRACKER USERS: A MIXED-METHODS EXAMINATION

SUMMARY

Wearable fitness trackers (WFTs), like Fitbits, are intended to support physical activity (PA) engagement. It is unclear, however, how WFTs influence both PA and motivation for PA as described by the Self-Determination Theory (SDT). This study examined PA and PA motivation in former and current WFT users using a mixed-methods design, consisting of a survey and semi-structured interviews. The survey included items from the Global Physical Activity Questionnaire (GPAQ) to assess PA and Behavioral Regulation in Exercise Questionnaire version 3 (BREQ-3) to assess motivation. A sample of 288 participants (173 current vs. 115 former users) completed the survey and 17 participants (10 current vs. 7 former users) participated in interviews. Quantitative results indicated that current and former users did not differ in measures of PA. Current users scored higher on introjected regulation and identified regulation for PA. Qualitative results indicated that current users used the device to collect data, rather than for motivation. Former users reported that the WFT had little impact on their PA,

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Motivation for Physical Activity and Physical Activity Engagement in Current and Former Wearable Fitness Tracker Users: A Mixed-Methods Examination

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doubted the device accuracy, and reported feeling guilty when they did not meet WFT goals. We also provide hypothesized models of factors that contribute to persistent WFT use and factors that contribute to abandonment as they pertain to PA motivation and engagement.

Background

Fewer than a third of American adults meet the Centers for Disease Control and Prevention guidelines of at least 150 minutes of moderate or 75 minutes of vigorous physical activity (PA) per week.[22] This level of inactivity carries with it elevated disease risk, an increased risk for all-cause mortality, and a social and economic burden associated with rising health care costs.[22] Wearable fitness trackers (WFT) such as the Fitbit and the Apple Watch, were developed to support inactive individuals in improving their PA engagement, and subsequently their overall health.[72] WFTs are small, fairly low-cost, wrist- or hip-worn devices that provide the user with data like number of steps taken, calories burned, or minutes of exercise completed.[72] It has been well documented that WFTs are extremely popular among consumers, with 77.85 million units sold worldwide in 2019.[4]

Although millions of consumers purchase WFTs each year, research has shown that at least one third of WFT users abandon the devices within six to twelve months of acquisition.[5] In fact, one study found that half of new Fitbit users stopped using the device within the first two weeks of device ownership.[79] As such, it is unclear as to why WFTs users purchase, and then abandon the devices and how WFTs influence PA participation for both those who persist with use or abandon the devices.[14] Furthermore, it is unknown how WFTs influence an important mediator for PA, motivation, in current and former users.

Motivation for PA can be examined using the Self-Determination Theory (SDT), a theory of behavior change. According to SDT, humans have three psychological needs: autonomy,

competence, and relatedness.[6] Autonomy is the need to exercise choice over one's behaviors, competence is the desire to improve skills and master a behavior, and relatedness is the need to feel socially connected to others.[6] When these needs are fulfilled, a person is able to move along a motivation continuum from more controlled forms to more autonomous forms.[7]

Behaviors which are untaken solely for enjoyment are said to be driven by the most autonomous form, intrinsic motivation.[7] On the other end of the continuum lies amotivation, in which a person is disinterested in the behavior.[7] In between these two extremes lie four other subtypes of motivation: external regulation, introjected regulation, identified regulation, and integrated regulation.[7] Externally regulated behaviors stem from a desire to be compliant, to conform, or to receive external rewards or avoid external punishments.[7] Introjected regulation refers to motivation that is grounded in a drive for self-control, a need to protect one's ego, or to receive internal rewards or avoid internal punishments.[7] Identified regulation of behavior occurs when the motivation is somewhat internal and is based on conscious values.[7] The most internalized form of extrinsic motivation is integrated regulation which is driven by intrinsic sources such as the desire to act in congruence with one's values and sense of self.[7]

In relationship to PA, more autonomous forms of motivation are associated with persistent engagement in moderate to vigorous PA.[6,8] WFTs are thought to support SDT-based motivation for PA by the fulfillment of psychological needs.[9] A number of research groups have assessed behavior change techniques that can impact psychological needs found in different WFT models,[80-83] including Apple Watches and Fitbits, two of the most popular brands.[84] All devices studied were found to have embedded features that aligned with providing feedback and self-monitoring of behavior.[80-83] Both feedback and self-monitoring have the potential to enhance competence for PA.[9] Further, the most popular WFTs no longer only track steps. They allow the

user to choose from a variety of PA modes like swimming, dance, golf, strength training, and more.[10,11] Importantly, providing the opportunity for choice can enhance autonomy for PA.[12,13]

Theoretically, then, WFTs should support more autonomous forms of motivation for PA in WFT users. However, it is unclear if this is the case. To our knowledge, no data exists as to the motivation for PA and PA engagement in current versus former WFT users. Therefore, the purposes of this study were to assess and describe how current and former WFT users differ in their PA engagement and motivation for PA as described by SDT.

Methods

Study Design

This study implemented a mixed methods approach with two sequential phases: a quantitative arm, a survey, followed by a qualitative arm, semi-structured interviews. The study protocol was approved by the Institutional Review Board of Colorado State University (protocol 19-9256H).

Quantitative Arm

Procedures

Participants were recruited via social media platforms, emails, and course announcements at a large state university in the western United States. Interested participants were directed to an online link where they first responded to two screening questions to determine their eligibility. To be included in the study, participants must have responded "Yes" to both: "Are you over the age of 18?" and "Do you currently use a wearable fitness tracker or have you used one in the past?" Based on the responses to the latter question, participants were categorized into two study groups: current and former WFT users. Ineligible participants were exited out of the survey whereas eligible participants were directed to a screen with a statement of informed consent and statement

of agreement. Those who provided consent were directed to the online survey hosted on the web-based platform, Qualtrics (Provo, UT). An a priori power analysis was conducted using G*POWER[85,86] to test the main effect of group, controlling for up to six covariates, with a medium effect size (f=0.25), and an alpha of 0.05. A sample of 270 participants was required to achieve 0.80 power in the quantitative arm. Quantitative data were collected between October 2019 and April 2020.

Measures

First, we developed a seventy-five-item survey that included the validated Global Physical Activity Questionnaire (GPAQ) to assess weekly moderate to vigorous PA (MVPA) and sedentary time.[87] Motivation for PA was measured using the validated Behavioral Regulations in Exercise Questionnaire-version 3 (BREQ-3),[88,89] which assesses each of the six SDT subscales (amotivation, external regulation, introjected regulation, identified regulation, integrated regulation, and intrinsic motivation) on a five-point Likert scale. In addition, we assessed participant demographics and anthropomorphic measurements. Three SDT experts reviewed the survey items before ten lay people tested the survey in its entirety. Both expert and lay feedback was incorporated into the final survey version. The final survey is included in Appendix A.

Data Analysis

To test the internal consistency of the motivation subscales, we calculated Cronbach's alphas and found each subscale to be above the acceptable alpha value of 0.70[90] with a range of 0.75 – 0.92 (See Supplementary Table 1). We calculated body mass index (BMI) using participant reported height and weight with the formula: BMI= kg/m^2. We used each motivation subtype score to calculate Relative Autonomy Index (RAI)[91] with the formula:

Intrinsic+Integrated+Identified-Introjected-External-Amotivation.[92] Although some argue that RAI is not an appropriate metric of motivational quality[93], Sheldon and colleagues[92] vigorously tested RAI and determined that it is both an effective and parsimonious way to describe overall motivation.

Means, standard deviations, and proportions were calculated for demographic variables, motivation subtypes, and RAI. Student's t-tests were used to compare means of continuous variables between groups. We calculated two-proportion z-tests to identify differences in categorical variable proportions between groups (current and former WFT users).

Using a series of multiple regression analyses and, when appropriate, Tukey's HSD post-hoc analysis, we investigated between group differences for PA and motivation variables. We also tested for interaction effects of potential covariates and group on each outcome variable. To select each model, we first tested for a main effect of each potential covariate on each outcome variable. When a main effect was identified, we included that variable in the model as a covariate. After fitting each model, we examined diagnostic plots to assess linearity, distribution of residuals, and heteroscedasticity and found all of the models met the assumptions of normality. We also used the Bonferroni Outlier Test to identify data points with large studentized residuals. We identified one significant outlier in two models (amotivation and identified regulation) and removed those data points from analyses. The significance level was set to $p<.05$ and all analyses were conducted in R version 4.0.2.[70]

Qualitative Arm

Survey Items

We developed fifteen interview questions with the intention of using a semi-structured protocol. The survey questions are included in Appendix A.

Participants

Following the quantitative data collection, a separate sample of interview participants was recruited. Interested participants emailed our team and arranged a date and time for either an in-person, telephone, Skype, or FaceTime interview. Participants provided informed consent and the interviews were audio recorded. Interviews were conducted between January 2, 2020 and March 17, 2020. After drafting the study findings, we emailed a draft to each participant and invited them to provide feedback regarding the presentation of their quotes and our interpretations.

Data Analysis

We transcribed all interviews verbatim and conducted thematic analyses using an inductive approach.[94] Two researchers read each transcript several times independently, coding the transcripts for emerging themes using NVivo 12 software (QSR International, Melbourne, Australia). Through a series of discussions, main themes were identified by grouping similar codes together into broader categories. Researchers modified and refined the themes until both were satisfied that the final set accurately represented the participants' attitudes and opinions.

Researcher Positionality

Typically, in qualitative studies, the researcher who conducts the interviews reveals his or her unique positionality, or aspects of her identity that may influence the interpretation of the interview data. The first author is a person who uses a WFT for tracking exercise, which may have influenced the data interpretation.

Results

Quantitative Results

Figure 2 shows the number of participants per group who completed each survey section. Of the initial 289 respondents, 288 provided informed consent and completed the online survey;

173 were current and 115 were former WFT users. Of the initial 289 respondents, 288 provided informed consent and completed the online survey; 173 were current and 115 were former users.

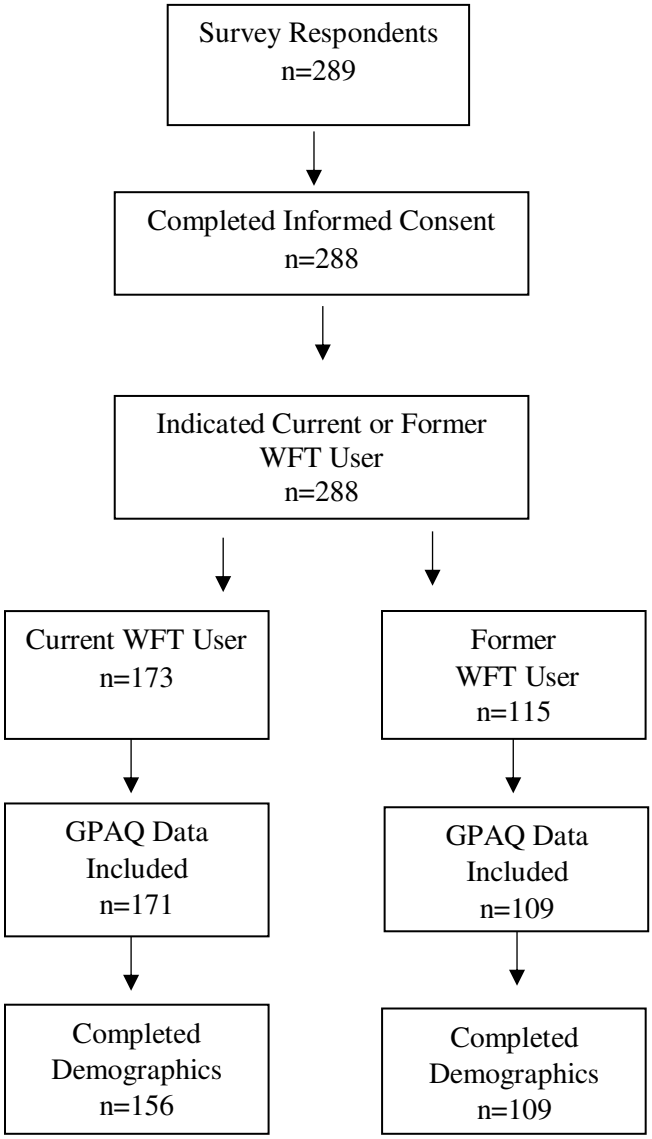


Figure 2. Total Number of Survey Respondents and Number of Current vs. Former WFT Users Who Completed Each Survey Section

Table 5 shows descriptive information of WFT current and formers users including age, sex, race, education, income, health perception, proportion meeting MVPA recommendations, and BMI. There were no significant differences between current and formers users in proportions

or means for most variables except the proportions of males, females, White people, participants who had some college or graduate degree, and participants whose income was <$12,500 and between $30,000 and $43,999.

Table 5. Means and Standard Deviations of Age and BMI and Counts and Percentages of Other Demographic, Health, and PA Variables in Current and Former WFT Users

Variable	Former Users (n=109)	Current Users (n=159)	*p* Value
Age	37.31 (11.87)	34.68 (13.42)	.10
BMI	25.99 (4.69)	26.66 (9.24)	.32
Sex			
Males	15 (13.76%)	9 (5.77%)	**<.05**
Females	94 (86.24%)	147 (94.23%)	**<.05**
Race			
White or Caucasian	103 (94.50%)	136 (87.18%)	**<.05**
Black or African American	1 (.92%)	3 (1.92%)	.89
Asian	2 (1.83%)	9 (5.77%)	.21
Native American or American Indian	1 (.92%)	1 (.64%)	1.00
Other	0 (0.00%)	4 (2.56%)	.25
Do not know/Prefer not to answer	1 (1.83%)	2 (1.28%)	1.00
Education			
12th Grade or Less	0 (0.00%)	1 (.64%)	1.00
High School or GED	3 (2.75%)	9 (5.77%)	.39
Some College/AA/Technical Degree	15 (13.76%)	57 (36.54%)	**<.0001**
College Graduate	37 (33.94%)	47 (30.13%)	.60
Graduate Degree	54 (49.54%)	42 (26.92%)	.001
Income			
Less than $12,500	7 (6.42%)	30 (19.23%)	**<.01**
$12,500-29,999	13 (11.93%)	15 (9.62%)	.66
$30,000-$43,999	19 (17.43%)	12 (7.69%)	**<.05**
$44,000-$59,999	19 (17.43%)	23 (17.74%)	.64
$60,000-$74,999	7 (6.42%)	12 (7.69%)	.91
$75,000-$99,999	11 (10.09%)	19 (12.18%)	.77
$100,000-149,000	12 (11.01%)	21 (13.46%)	.72
More than $150,000	2 (1.83%)	4 (2.56%)	1.00
Do not know/prefer not to answer	18/109	18 (11.54%)	.31
Participants Meeting MVPA Recommendations	95 (87.15%)	152 (88.89%)	.80
Perception of Own Health			
Excellent	11 (10.09%)	15 (9.62%)	1.00
Very Good	36 (33.03%)	66 (42.31%)	.26
Good	42 (38.53%)	48 (30.77%)	.16
Fair/Poor	20 (18.35%)	26 (16.67%)	.68
Do not know/prefer not to answer	0 (0.00%)	0 (0.00%)	1.00

When comparing current and former WFT users, the only statistically significant differences between groups are a higher proportion of former WFT users used Fitbits and a

higher proportion of current WFT users used an Apple Watch. No other variables differed significantly between groups (Table 6).

Table 6. Means and Standard Deviations of Number of WFTs Used and Counts and Percentages of Current or Most Recently Used WFT Device Type, and Length of Time Current or Most Recent WFT Was Used in Current vs. Former WFT Users

Variable	Former Users n=115	Current Users n=173	*p* Value*
Number of WFTs Owned	1.23 (0.47)	1.11 (0.34)	**<.05**
Current or Most Recent Device Type			
Fitbit	89 (77.39%)	83 (47.98%)	**<.001**
Apple Watch	7 (6.09%)	57 (32.95%)	**<.0001**
Garmin	9 (7.83%)	19 (10.98%)	.49
Samsung	1 (.87%)	6 (3.47%)	.31
Other	10 (8.70%)	8 (4.62%)	.72
Length of Use of Current or Most Recent Device			
Less Than One Month	6 (5.22%)	3 (1.73%)	.19
One to Three Months	14 (12.17%)	11 (6.36%)	.14
More than Three Months	95 (82.61%)	155 (98.60%)	.09
Unknown	1 (.87%)	4 (2.31%)	.65

*results of two-proportions z-tests to test differences between current and former WFT users

When reporting device features, 230 participants reported that steps were counted by their WFT, 172 reported active or exercise minutes were counted by their WFT, 106 reported that energy expenditure was assessed by their WFT, 100 reported that hours of sleep were assessed by their WFT, and 57 reported that hours in which they stood for at least one minute were counted by their WFT. Twenty-eight participants reported other features of their WFTs like estimating energy intake or measures of stress.

The most frequent reasons for abandoning a WFT were, “It broke,” “It did not help me meet my goals,” and “It got boring” (Table 7). A large number of former users reported that their PA levels “increased a little” (n=58, Figure 3). Of those, 28 reported their PA “decreased a little” after discontinuing WFT use, 23 reported “no change” after discontinuing use, and 4 reported

their PA "decreased a lot" after discontinuing use. The second highest number of respondents (n=33) reported "no change" in the PA after WFT adoption. Of those, 30 reported "no change" after WFT abandonment.

Table 7. Reasons Former WFT Users Discontinued WFT Use

Reason	Frequency
It broke	29
It did not help me meet my goals	15
It got boring	14
I did not like it	10
I learned everything I could from it	9
It was intrusive	8
Device negatively impacted my mental health (made me feel guilty, etc.)	7
Device was uncomfortable	5
I became less active for a reason not attributable to the device (injury, etc.)	5
I lost the charger/Charging it was prohibitive	5
I lost it	3
Data privacy concerns	3
Device became outdated	2
Do not know/Prefer not to answer	1

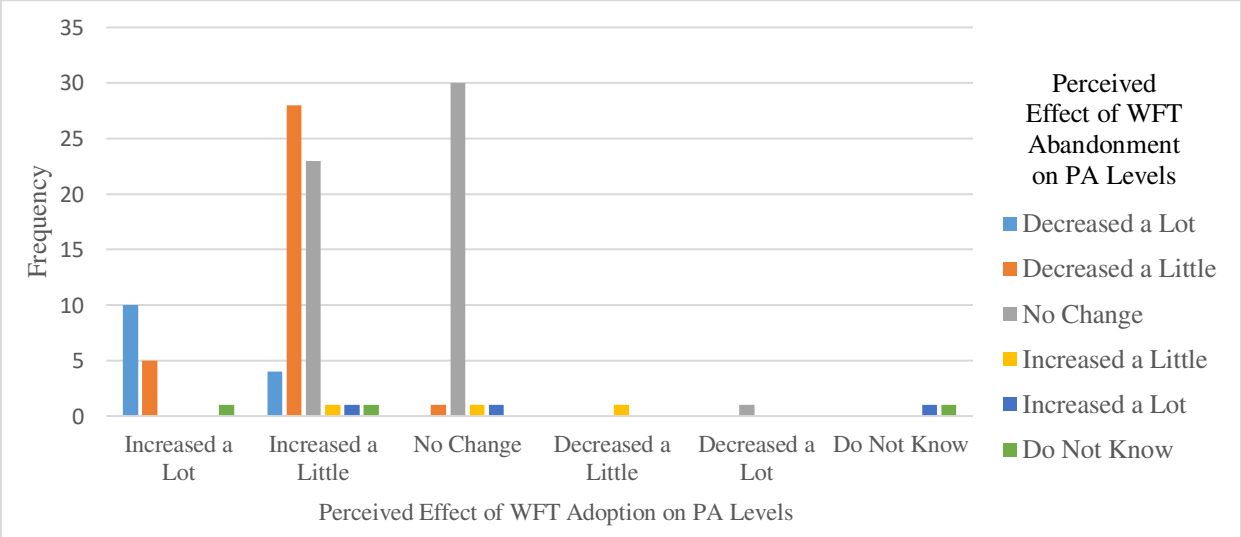


Figure 3. Former Users' Perceptions of the Impact of WFT Adoption and WFT Abandonment on their PA Levels

We detected significant group main effects on introjected regulation ($F(1,286)=8.36$, $p<.001$) with current users (2.51±0.82) scoring higher than former users (2.42±0.93; Table 8). When controlling for health perception, there was also a significant main effect of group on integrated regulation of ($F(1,281)=12.99$, $p<.0001$) with current users scoring higher (2.80 ± 0.85) than former users (2.63 ± 0.85). No other effects of group were seen among PA motivation outcome variables. In assessing MVPA and sedentary minutes per week, former users reported more sedentary minutes per week (3378.26±1445.47) than current users (2745.87±1319.93) when controlling for BMI ($F(1,253)=18.86$, $p<.0001$). There was no statistically significant difference in MVPA minutes per week between groups.

Table 8. Comparison of BREQ-3 Subscales and MVPA and Sedentary Minutes Per Week in Current and Former WFT Users

	Former User Mean (sd)	Current User Mean (sd)	F Value	Pr(>F)
Amotivation*@	0.41 (0.48)	0.44 (0.42)	1.77	.18
External Regulation**	0.99 (0.80)	1.13 (0.85)	1.21	.27
Introjected Regulation	2.42 (0.93)	2.51 (0.82)	8.36	**<.001**
Identified Regulation*@	3.32 (0.60)	3.33 (0.59)	0.0029	.96
Integrated Regulation *	2.63 (0.85)	2.80 (0.85)	12.99	**<.0001**
Intrinsic Motivation *	2.91(0.77)	3.02 (0.76)	1.00	.32
Unweighted Relative Autonomy Index*	5.10 (2.73)	5.07 (2.81)	0.25	.62
MVPA Minutes/Week	683.16 (678.71)	885.05 (1302.82)	0.31	.58
Sedentary Minutes/Week***	3378.26 (1445.47)	2745.87 (1319.93)	18.86	**<.0001**

Notes: *= controlling for health perception and BMI, **= controlling for age, ***=controlling for BMI, @= with outliers removed, sd=standard deviation

Qualitative Results

Among current WFT users, six participants were female and one was male; whereas among former users, six participants were female and four were male (Table 9). Ages of current WFT users ranged from 28 to 50 years old and ages of former WFT users ranged from 28 to 51 years old. Six current users had only used one brand of WFT whereas one current user had tried

three. Length of use for current users ranged from 9 months to 6 years. Seven former users had only used on brand of WFT, one had experience with two brands, and one had experience with three brands. Length of use for former users ranged from 3 months to 4 years.

A number of themes emerged from these data among both current and former WFT users including: high levels of PA engagement, mental health benefits of PA as motivation, physical health benefits of PA as motivation, and the utility of WFTs for PA motivation. Among current users, a theme of the importance of tangible PA data emerged. Among former users, frustration with inaccuracy of WFT data and negative emotions around not meeting WFT goals emerged as themes. Each of these themes are described in the following sections.

Table 9. Participants Characteristics, Specific WFT Devices and Length of Time Devices Were Used by Participants in the Interview Protocol

Current Users				
Name	Sex	Age (years)	Device	Length of Time Used
Mindy*	Female	40	Fitbit	1 Year
Reece*	Female	35	Fitbit	2 Years
Sasha*	Female	33	Fitbit	5 Years
Skyler*	Female	25	Fitbit, Garmin, Apple Watch	4 Years
Stella*	Female	42	Apple Watch	6 Years
Wayne*	Male	50	Fitbit	3 Years
Cammy*	Female	28	Apple Watch	9 Months
Former Users				
Jamie*	Female	42	Fitbit	6 Months
Jeremy*	Male	31	Fitbit	3 Months
Jake*	Male	48	Fitbit	4 Months
Lila*	Female	37	Jawbone and Fitbit	2 Years
Noah*	Male	28	Fitbit	1 Year
Renee*	Female	34	Apple Watch, Fitbit, and Garmin	2 Years
Rachel*	Female	55	Fitbit	2 Years
Sadie*	Female	40	Apple Watch	4 Years
Tom*	Male	29	Fitbit	2 Years
Sofia*	Female	32	Misfit	1.5 Years

Note: *=pseudonym

PA Routine

Both former and current WFT users reported having a PA routine that involved at least three days per week of PA for at least 30 minutes per bout. Participants reported engaging in a number of different modes of PA including walking, yoga, strength training, swimming, cycling (indoor and outdoor), cardio equipment, group exercise classes, and participation on athletic teams. For example, Mindy, a current user stated, "I have a trainer who loads exercising in an app and I go to the gym and do them. There are about 5 days of weights. I also practice Muay Thai and Brazilian Jiu Jitsu and I do Pilates occasionally." Jamie, a former user, said, "I ride my Peloton bike every day and try to go swimming at least 3 times a week." Overall, this sample of interview participants appeared to be physically active, regardless of their status as a current or former WFT user.

Mental Health Benefits of PA as Motivation

Across groups, almost all participants discussed the mental health benefits and overall sense of wellbeing they experience when they are physically active. More than one participant mentioned mood enhancement, feeling accomplished, and managing mental health conditions as effects of PA. According to Mindy, a current WFT user, "(Exercise) keeps the crazy at bay; my mood is vastly improved when I exercise. I feel accomplished by setting a goal to go to the gym and keeping it. It's me time." Noah, a former WFT user said, "My motivation for exercise is the positive mental boost it provides, and this usually begins during exercise and lasts well after it ends." This was echoed by Tom, another former user who said, "Exercise is great for my mood. I like to remind myself how good I am going to feel afterward."

Physical Health Benefits of PA as Motivation

Interview participants discussed the physical health benefits of PA and how those also are motivators for PA. Some participants general discussed physical health, like Cammy, a current

user who said, “I don't give a (expletive) about being skinny but having a healthy body and a healthy heart are very important to me.” Others discussed more specific health outcomes like Wayne, a current user who said, “(I exercise for) prolonged life, fighting back family gene challenges like diabetes and high blood pressure.” A few participants also spoke about body weight and weight management. Noah, a former user said, “I understand the importance of physical activity and its relationship with health so I am motivated by that as well. Finally, I absolutely love food and do not necessarily restrict what I eat, so exercise is a means to keep my body in check. I always tell people, ‘I engage in physical activity because I love to eat.’”

Utility of WFTs for PA Motivation and Decreasing Sedentary Time

Eight of ten former WFT users and three of seven current WFT users discussed how their WFT encouraged them to move a bit more from day to day. Most respondents talked about seeing their progress toward their WFT goal, like daily steps, and being motivated to complete those goals. Stella, a current user said, “I'm definitely better about making sure I move when I'm wearing it. I like seeing my (Apple Watch) circles close!” Other respondents discussed the WFT reminders to move every hour. As Jamie, a former user said, “The reminders to move around were useful when I was not doing much.” Similarly, Skyler, a current user said, “It is a reminder to get moving when I have not.”

Importance of Tangible PA Data

Most current WFT users reported that they did not necessarily consider their WFTs to be motivating for PA. Instead, six current users discussed the utility of their WFT to collect and visualize data about their PA. As Cammy, a current user said, “I never really focused on the (step) goal. I was just interested in seeing what I did.” Similarly, Sasha, a current user said, “It

doesn't really motivate me to exercise. It's just helpful to know how active I am in my normal day to day."

Frustration Regarding Accuracy

Three of the ten former WFT users found themselves to be frustrated by the apparent lack of accuracy in the metrics assessed by their WFT. Noah, for example, talked about how the activities he enjoyed the most were not the ones that, historically, his WFT was able to track. He said, "I did not consider the goals set by Fitbit to be very important, especially as it was not particularly accurate when doing activities other than walking or running, like cycling, which I engaged in much more during the period I wore the device."

Negative Emotions Due to Failure to Meet Goals

Four of the ten former WFT users also discussed the emotional impact during periods of time in which they could not complete their WFT goals. Lila, for example, described her experience after becoming pregnant. She said, "Toward the end of using the tracker, I got pregnant and was struggling with energy, nausea, etc. It became difficult to meet the goals and it was depressing to see streaks of not making the goals… and I felt even guiltier ignoring it, so I took it off." Sadie discussed using her WFT to stave off weight gain, however the byproduct was negative emotions. She said, "I found after 4 years of using one that it didn't motivate me anymore, it only made me feel bad when I didn't (meet my goals)… But the weird thing was before the tracker, I never felt bad if I didn't get a workout in- there was always tomorrow."

Discussion

The study reported here used quantitative and qualitative methods of data collection and analyses in a mixed methods approach to examine the differences in PA and PA motivation

between former and current WFT users. In both the quantitative and qualitative arms of this study, current and former WFT users reported regular engagement in weekly MVPA. In interviews, most participants discussed the mental and physical health benefits that they experienced through having an exercise routine. Also, both current and former users reported high levels of both identified and integrated regulation for PA, which can be associated with a desire to maintain good health.[8]

Sedentary Time and Wearable Fitness Trackers

Whereas we did not detect significant group differences in MVPA engagement, current WFT users reported a significantly lower number of sedentary minutes than did former WFT users according to survey data. Qualitative data supported this finding as 80% of former users and 43% of current users discussed the usefulness of their WFT to interrupt their sedentary time. Many WFTs, such as Fitbit[95] and Apple Watch[96] devices have features that prompt the user to stand at least once per hour and take 250 steps, in the case of the Fitbit, or remaining standing for a minute, in the case of the Apple Watch. According to Scheid and West[97] these prompts are self-management strategies, which is an impactful behavior change technique. A number of reviews and meta-analyses[98-100] as well as original studies[101] suggest that WFTs can support reductions in sedentary time in different populations.

Wearable Fitness Trackers Use and Motivation for Physical Activity

In our sample, current WFT users scored highly on measures of both introjected (more controlled) and integrated (more autonomous) motivation for PA. These results mirror those of Friel and Garber,[102] who surveyed current WFT users about motivation for PA, using a method called cluster analysis to define their participants. One identified cluster "High Introjected and High Autonomous" show the greatest level of MVPA in the sample. This cluster also represented

the largest number of participants in the study, suggesting that persistent WFT users tend to high in both controlled and autonomous forms of motivation.

These findings are especially compelling because feedback from WFTs can have varied effects on the user's motivation, depending on a number of factors like how the user perceives that feedback.[103,104] If feedback is perceived as emphasizing user competence, it can increase autonomous motivation for the behavior.[104,105] However, if feedback is perceived as pressure to behave a certain way, it can decrease autonomous motivation for the behavior.[103,105] Therefore, feedback from a WFT can either increase autonomous motivation for physical activity, for example, or create dependency on the device, decreasing autonomous motivation.[106] Behavior can become less likely due to the suppression of autonomous motivation.[107] Kerner and Goodyear saw this very effect in a sample of adolescents who were given Fitbits.[37] In our case, however, persistent WFT use is associated with both high controlled (introjected) and high autonomous (integrated) motivation.

One explanation may lie in the traits of individuals who use WFTs over long periods of time. Dialectical thinking, the ability to hold two contradicting thoughts at the same time, is thought to be protective against the reduction in autonomous motivation due to external rewards or feedback.[108] These individuals may view their autonomous motivation for the behavior and their extrinsic motivation due to a reward or feedback to be unrelated.[106] In the case of our sample, then, current WFT users experienced increased introjected regulation for PA due to the feedback from the device but this did not appear to impact their autonomous motivation for PA, nor their PA engagement.

A second trait, the need for cognitive closure or the desire for clear-cut answers, predictability, order, and avoidance of ambiguity, is associated with a greater need for feedback

and has little impact on autonomous motivation.[106] On the other hand, people with low need for cognitive closure, do have their autonomous motivation negatively impacted from feedback on performance.[109] Our qualitative sample of current WFT users expressed the importance of using their WFT to quantify their PA behaviors, seeking cognitive closure with little impact on their autonomous motivation.

We also noted that current WFT users were not particularly motivated by their WFTs, but rather appreciated the ability to visualize their PA data. Device-based self-monitoring, or simply recording behavior, is associated with increased competence and autonomous motivation for PA.[110,111] There is overwhelming evidence that both competence and autonomous motivation are associated with increased PA engagement.[8] Whereas our sample of current users did not identify self-monitoring (i.e. visualizing their data) as a contributor to their motivation or PA, we speculate that there is an association between these variables in this group.

A third trait, autonomy causality orientation, can also be protective against the decrease in autonomous motivation due to external rewards or feedback.[112,113] Autonomy causality orientation is associated with seeking to engage in a behavior out of personal choice. Conversely, individuals with a control causality orientation perceive actions to be controlled by externally pressuring events. These individuals tend to persist in behaviors only as long as those pressuring events are present.[113] In our qualitative sample, a number of former users discussed feeling pressure to complete their WFT goal and many would do extra exercise at odd times of the day in order to relieve that pressure. We speculate, then, that these formers users had a control causality orientation toward physical activity.

Other protective traits include affinity for technological interaction, or the tendency of an individual to actively explore new technology.[114] Also, an individual's achievement motivation

can be protective. An approach tendency, which is described as engaging in a behavior with hope for success, is protective, whereas avoidance tendency or fear of failure is not.[115] A high approach tendency is linked to mastery goals like deepened knowledge or mastering challenging learning material and is positively associated with autonomous motivation.[116,117] A high fear of failure is associated with an avoidance tendency and is negatively associated with intrinsic motivation for behaviors.[117]

In our qualitative sample, a number of former users expressed negative emotions like guilt or feelings or failure when they did not meet their WFT goals. These findings are also reflected in a survey of 200 Fitbit wearing women.[118] In that sample, many respondents felt pressure to reach their Fitbit targets and that their daily routines were controlled by the device.[118] A third felt like their Fitbit was an "enemy" that made them feel guilty for not meeting their goals.[118] If participants were NOT wearing their Fitbit, however, they felt that the activities they completed were "wasted" and some felt less motivated to exercise at all.[118] This phenomenon is termed the "dependency effect."[106] Attig and Franke[106] determined that people more autonomously motivated for exercise were less likely to experience the dependency effect (i.e. not exercise if they did not have their tracker).

Hypothetical Models of Current and Former Wearable Fitness Tracker Users

Given the results of the current study, we hypothesize that WFTs are useful to support persistent PA in certain types of people, but not all. The ideal WFT user will experience increased introjected regulation (controlled regulation), potentially due to WFT feedback. The traits of WFT users including autonomy causality, dialectical thinking, mastery approach tendency, need for cognitive closure, and affinity for technological interaction may protect PA levels from the negative effects of increased controlled regulation. Increases in PA engagement,

then, will support the development of more autonomous forms of motivation, like integrated regulation. Positive feedback from the device can also increase intrinsic motivation for WFT goal completion, as seen in our sample, feeding back and increasing device use. Figure 4 depicts this relationship.

We also hypothesize that some people who begin using WFTs and ultimately abandon them perceive that the device has very little effect on their PA and may be skeptical as to the accuracy of the WFT data. They also may experience increased introjected regulation as a result of device feedback. They can become overwhelmed by associated feelings of guilt or shame as indicated by our qualitative results. Without the protective traits, these individuals may choose to abandon the device. Figure 5 depicts this relationship.

Limitations

This study is not without at least one limitation. First, a portion of the survey data were collected during the initial months of the Covid-19 global pandemic. Interestingly, only 20% of current WFT users who responded to this survey did so after the declaration of a national emergency in the United States (March 13, 2020) whereas 68% of former WFT users who responded to the survey did so after March 13. However, we categorized response date into pre- and post-national emergency groups and tested this variable in each of our models. It, in fact, was not associated with any of our outcome variables. It is important, however, to acknowledge this as a limitation as early data suggests that reductions in moderate, vigorous, and walking PA were prevalent in US adults during the Covid-19 pandemic.[119]

A second limitation to this study lies in the items included in the survey. We did ask former WFT users about how their device usage and subsequent abandonment impacted their PA levels. We did not, however, include this question regarding WFT use and impact on PA in the

version of the survey intended for current users. As such, we are unable to compare perceptions of the impact of WFT use on PA levels between groups.

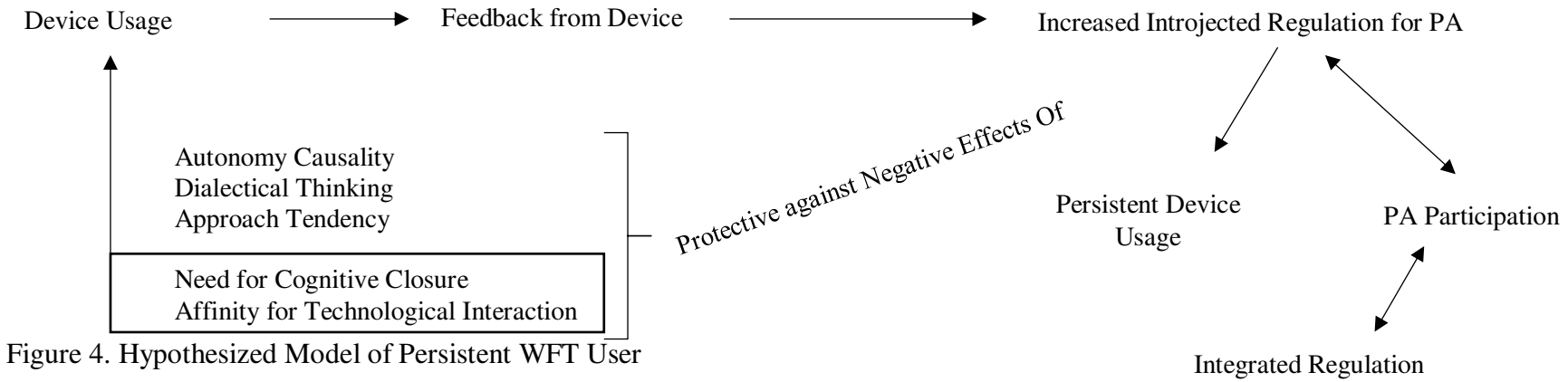


Figure 4. Hypothesized Model of Persistent WFT User

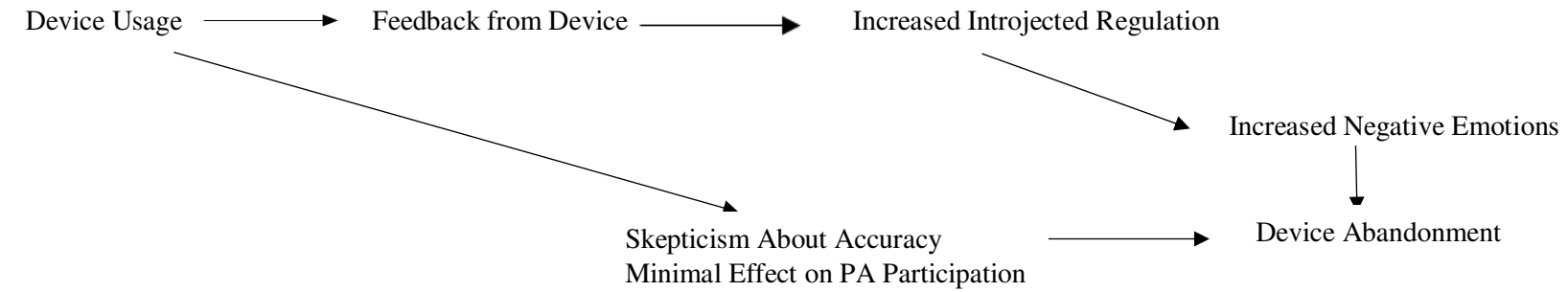


Figure 5. Hypothesized Model of Former WFT User

Conclusion and Future Directions

In this mixed methods study, we determined that there are statistically significant differences in sedentary time and in introjected and identified regulation for PA. We also found that both current and former users met recommended physical activity levels and had high levels of autonomous motivation for PA. Current users reported that they did not necessarily consider themselves motivated by their WFT, but rather appreciated visualizing their PA data. Former users reported that they stopped using their devices after more than three months mainly because the device broke, the device did not support PA goal completion, or the device got boring. A subset of former users also reported having negative impacts on their mental health due to their inability to meet their WFT goals. Others doubted that WFTs assess PA accurately. Former users, however, do not have lower PA participation than current users.

We hypothesize that a set of personality traits, such as autonomy causality, dialectical thinking, high approach tendency, need for cognitive closure, and affinity for technological interactions may protect some people against the negative effects of increasing controlled motivation due to WFT feedback. These individuals persist with WFT use and with PA engagement. However, it is unclear to what degree the WFT affects their PA levels.

We suggest that future studies assess autonomy causality, dialectical thinking, high approach tendency, need for cognitive closure, and affinity for technological interaction in current and former WFT users. If current users score higher in these variables, we anticipate that these data can be used to determine *who* is most suited for a PA intervention using WFTs. Health professionals can then screen patients for these traits to determine if a WFT might be an impactful intervention to increase PA in underactive people.

CHAPTER 5- THE COMBINED EFFECT OF MOTIVATIONAL INTERVIEWING AND WEARABLE FITNESS TRACKERS ON MOTIVATION AND PHYSICAL ACTIVITY IN INACTIVE ADULTS DURING THE COVID-19 PANDEMIC: A RANDOMIZED CONTROLLED TRIAL

Background

In late 2019, a number of community members from Wuhan, Hubei Province in China fell ill from a novel coronavirus.[120] On January 30, 2020, the World Health Organization declared the outbreak to be a public health emergency and on March 11, a pandemic.[120] On March 13, 2020, President Donald Trump declared the COVID-19 outbreak in the United States to be a national emergency.[120] In response to the declaration of a national emergency, the federal and various state governments issued guidelines to limit the spread of COVID-19. The federal government ordered social distancing, encouraging Americans to avoid congregating in groups of more than ten people at a time, while maintaining a distance of six feet in between any two people.[121] As of April 7, 2020, forty-one states had some form of stay-at home order in place.[122]

Physical Activity (PA) and Health

Early evidence suggests that the pandemic and associated stay-at-home orders had a detrimental effect on health behaviors, like physical activity (PA).[123] Prior to the pandemic, already more than two thirds of U.S. adults did not meet the Centers for Disease Control and Prevention (CDC) recommendation of 150 minutes of moderate-intensity physical activity (MPA) per week, or 75 to 150 minutes of vigorous intensity physical activity (VPA) per week, or some combination of both.[1] Insufficiently active individuals have a 67% higher risk for all-cause

mortality and contribute to the $117 billion dollars in health care costs associated with physical inactivity.[22]

Not only is physical activity associated with overall physical health; it also is likely a potent attenuator of negative outcomes of a COVID-19 infection.[124] Among the first known patients with COVID-19 who required hospitalization in Wuhan, China, half had underlying health conditions, like diabetes or hypertension, conditions that benefit from PA engagement.[125] Data from the United States,[126] Italy,[127] and Spain[128] substantiate this finding, adding that underlying health conditions also increased mortality risk in infected patients. Whereas health advocacy groups like the World Health Organization stress the importance of physical activity during the Covid-19 pandemic, and recommend modes like home exercise and exergames, research is lacking on the effectiveness of interventions intended to increase PA during this time.[129]

Self-Determination Theory of Motivation

Behavior change, like initiating a PA routine, can be instigated through approaches like external pressure, coercion, rewards, or incentives. [130] Lasting behavior change, however, is more likely to occur if the underlying psychological constructs are effected. For example, Self-Determination Theory (SDT), a frequently used framework to understand PA motivation, asserts that motivation is grounded in the fulfilment of three psychological needs: autonomy, competence, and relatedness.[6] According to SDT, autonomy as the need to self-govern or self-regulate, one's own behaviors and experiences, whereas competence is the need to master a skill or feel effective.[6] Individuals feel a sense of relatedness, the third psychological need, when they are socially connected and feel cared for by others.[6] Social context is a key feature of SDT in that environments which support the fulfillment of these basic psychological needs promote effective

functioning and behavior whereas environments that do not, will not. When the psychological needs are satisfied, people are able to move along the motivation continuum, from more controlled forms (external or coerced) to more autonomous (volitional) forms.

At one end of the motivation continuum lies amotivation that describes a state in which the individual is non-autonomous and has no drive for the behavior.[7] Following amotivation are the extrinsic forms, the most extreme of which is external regulation. Externally regulated behaviors stem from a desire to be compliant, to conform, or to receive external rewards or avoid external punishments.[7] Moving along the continuum, introjected regulation refers to motivation that is grounded in a drive for self-control, a need to protect one's ego, or to receive internal rewards or avoid internal punishments.[7] Identified regulation of behavior occurs when the motivation is somewhat internal and is based on conscious values. The most internalized form of extrinsic motivation is integrated regulation which is driven by intrinsic sources such as the desire to act in congruence with one's values and sense of self. Intrinsic motivation is the most autonomous form, with behaviors grounded in interest, enjoyment, and a sense of satisfaction.[7]

It may not be possible for every person to become intrinsically motivated to perform PA, but it is possible for individuals to move from amotivation to more autonomous engagement in PA.[24] A large body of research has identified that more autonomous forms of motivation (intrinsic and more internalized forms of extrinsic motivation) are associated with engagement in moderate to vigorous PA.[6] Specifically, identified motivation predicts PA adoption and intrinsic motivation predicts long-term participation.[8]

Wearable Fitness Trackers to Improve Physical Activity Engagement

One recommended tool to enhance PA participation during the COVID-19 pandemic is the use of a wearable fitness tracker (WFT) such as a Fitbit or Apple Watch.[131] The small,

relatively low-cost, and user friendly WFTs have been developed to support sedentary or under-active individuals in increasing their PA engagement.[25] Short term studies have indicated that WFT use increases both self-reported PA and objectively measured PA in adults.[30,31] However, this improvement is not sustained in a majority of individuals.[32-36,132] Furthermore, it is known that most WFT consumers discontinue tracker use within six months of purchase.[133] Therefore, it continues to be relatively unknown whether or not WFTs impact motivation for PA or PA behavior in the long-term.[132]

Multiple Behavior Change Techniques Are Better Than One

Combining a WFT with other behavior change interventions may improve its effectiveness. According to a review by Sullivan and Lachman,[14] the most effective strategy to increase PA and sustain that increase is to employ multiple behavior change techniques. Several studies have combined wearable tracker use with other interventions such as cash incentives for hitting goals,[34] challenges sent to participants via email,[33] and a mobile application loaded with an exercise program.[31] Specifically, we propose combining WFT use with a motivational interviewing (MI) intervention to improve PA motivation and engagement.

Motivational Interviewing and Physical Activity

MI is a person-centered form of engagement that encourages people to assess their own position on the motivation continuum, explore the reasons behind their position, and determine how to best shift from amotivation or ambivalence to a more autonomous position. While MI was not developed with SDT in mind, Deci & Ryan[134] point out that SDT and MI have historically been congruent, particularly with their emphases on autonomy support to make health-related decisions and changes. Specifically, both SDT and MI are focused on the central ideal of motivation and the development of internal motives, and the exposure and consideration

of externally imposed goals or pressures to act which have no personal meaning to the individual.[135] SDT constructs and MI, both on their own and combined, are effective in improving both motivation for PA and PA behavior in a range of age groups. A number of studies measuring changes in PA in response to an SDT-based intervention or MI, or a combination of the two saw statistically significant increases in PA.[40-45] Research has also indicated that SDT-based MI is a powerful intervention to shift motivation for PA from mostly extrinsic to mostly intrinsic.[40,48,49]

WFTs and MI: Potentially Powerful

To our knowledge, three studies[51,52,136] have assessed the impact of MI and a WFT to improve PA. Two determined combining MI interventions with WFT use significantly improved self-reported PA, body weight, and HDL cholesterol in African American men[52] and increased the likelihood of meeting daily step goals in adolescent-parent dyads.[51] The third saw decreases in PA in active individuals who were only given a WFT for 12 weeks whereas participants who were given a WFT and a low-dose of MI maintained their PA levels.[136] These results present an encouraging possibility for improving PA in sedentary adults: WFTs and MI. Given the popularity of wearable fitness trackers and the effectiveness of SDT based MI in increasing PA motivation and behavior, the combination of the two shows promise to improve the overall health of adults.[137] Therefore, the purpose of this study was to assess the impact of an MI intervention in combination with WFT use on motivation for PA and PA behavior during the initial months of the Covid-19 pandemic.

Methods

Participant Recruitment and Health Screening

Participants were recruited through a variety of means including flyers on the Colorado State University campus, social media, and mass emails. An a prior power analysis using G*POWER[85,86] indicated that in order to detect difference among four groups with 95% confidence, medium effect size, and .80 power for F tests, 32 participants in total were required. We sought to recruit 40 total participants in order to allow for attrition. This study was approved by the Colorado State University Institutional Review Board (protocol 19-9439H).

To be included in this study, participants must have been over the age of 18 and must not be meeting physical activity guidelines of at least 150 minutes of moderate physical activity per week. Participants had to own an Android or iPhone smartphone device and be willing to download a mobile application onto that device for use during the intervention. They also had to be willing to potentially wear a WFT and/or attend bi-weekly MI sessions at conducted over a video calling platform. Participants could not have a history of heart disease or diabetes, and could have no limiting conditions like concurrent cancer treatment, peripheral artery disease, orthopedic injury, or pain limiting arthritis. They could not seek to participate in other structured PA programs for the duration of the study, could not be pregnant or seek to become pregnant, and must not have been diagnosed with alcohol or substance abuse during the previous twelve months.

Prior to data collection, eligible participants provided informed consent. All consented participants completed baseline surveys and seven consecutive days of objective physical activity monitoring using the ActiGraph wGT3X-BT (ActiGraph, LLC, Fort Walton Beach, FL, USA). Those participants were then stratified by age (20-29 y.o., 30-39 y.o., 40-49 y.o., 50-59

y.o., and 60-69 y.o.) and sex (male/female) before being randomized to one of four conditions (WFT, MI, WFT+MI, or PA Education Control).

Allocation of Intervention Conditions

The participants were randomized to four conditions (groups) as follows:

Wearable Fitness Tracker (WFT): Individuals assigned to this experimental condition were given a WFT called the Fitbit Inspire (Fitbit Inc., San Francisco, CA) and were instructed to wear it for twelve consecutive weeks. They were also be instructed to download the corresponding mobile application on their smartphones. Each participant was trained by a member of the research team on how to utilize the WFT and mobile application. Participants were instructed to try to complete at least 150 minutes of PA per week. These individuals were also asked to set biweekly PA goals, which were entered into a web-based form. They also received a 30-minute general education session via video call about physical activity guidelines and strategies to reach the recommended amount of activity per week.

Motivational Interviewing (MI): These participants completed six biweekly MI sessions with a trained practitioner via a video calling platform over twelve consecutive weeks. Participants in this group were provided a logbook and were instructed to log their PA, with the goal of completing at least 150 minutes per week. These individuals were also asked to set biweekly PA goals, which were entered into a web-based form. They also received a 30-minute general education session via video call about physical activity guidelines and strategies to reach the recommended amount of activity per week.

Wearable Fitness Tracker plus Motivational Interviewing (WFT+): Participants in this condition received a Fitbit Inspire, and participated in six, biweekly MI sessions via video platform with a trained practitioner for twelve consecutive weeks. They were asked to set

biweekly PA goals that they entered into a web-based form. They were instructed to try to complete at least 150 minutes of PA per week. They also received a 30-minute general education session via video call about physical activity guidelines and strategies to reach the recommended amount of activity per week.

Education: These participants received a 30-minute general education session via video call about physical activity guidelines and strategies to reach the recommended amount of activity per week.

Outcome Measures

Motivation for Physical Activity

Motivation for PA was assessed using the Behavioral Regulation in Exercise Questionnaire (BREQ-3) and the Basic Psychological Needs in Exercise Scale (BPNES). The BREQ-3 is one of the most widely used in PA and exercise motivation research and has been validated in English speaking adults.[88,89] This 23 item questionnaire assesses the six subtypes of motivation as described by SDT and is scored on a five-point Likert scale ranging from 0 (not true for me) to 4 (very true for me). Example items include "I don't see why I should exercise" to assess amotivation, "I feel guilty when I don't exercise" to assess introjection, and "I exercise because it's fun" to assess intrinsic motivation. Motivation subtype scores are calculated by averaging the score of four survey items that correspond to each subtype. When the BREQ-3 was validated in English speaking adults, the Cronbach's alpha coefficients were 0.82, 0.81, 0.78, 0.92, 0.93, and 0. 85 for amotivation, external regulation, introjected regulation, identified regulation, integrated regulation, and intrinsic motivation, repectively.[88,89]

The Basic Psychological Needs in Exercise Scale (BPNES) assesses autonomy, competence, and relatedness as they pertain to PA and has also been validated for use in

adults.[138,139] Twelve items assess the subscales of autonomy, competence, and relatedness, with a five point Likert scale ranging from 1 (I don't agree at all) to 5 (I completely agree). Example items inclue, "I am able to meet the requirements of my exercise program," to assess autonomy, "I feel like exercise is an activity which I do very well," to assess competence, and "My relationships with the people I exercise with are very friendly" to assess relatedness. Pyschological needs subscale scores are calculated by averaging the four respective survey items. When the BPNES was validated in English speaking adults, the Cronbach's alpha coefficients were 0.75, 0.80, and 0.86 for autonomy, competence, and relatedness, respectively.[139]

We also used the six SDT subtypes of motivation to calculate the unweighted Relative Autonomy Index (RAI) with the formula: Intrinsic+Integrated+Identified-Introjected-External-Amotivation.[91,92] The range of possible values is -12 to 12 with higher, positive values indicating more autonomous motivation. Although some argue that RAI is not an appropriate metric of motivational quality[93], Sheldon and colleagues[92] vigorously tested the RAI and determined that it is both an effective and parsimonious way to describe overall motivation quality.

Physical Activity

Pre- and post-intervention PA was objectively measured by seven consecutive days of actigraphy using the ActiGraph wGT3x-BT activity monitor. We aimed to collect at least three weekdays and one weekend day of valid wear (8 hours) over the seven day period as recommended by a number of PA researchers.[140] Participants were instructed to wear the device during all waking hours on a provided elastic belt on their non-dominant hip for one week. They were also given a log to record times that they removed the ActiGraph for activities involving

submersion in water, and time to bed and wake time. MVPA minutes and steps per day, per weekday, and per weekend day were outcome variables of interest.

PA and Steps Assessed by Fitbit

We accessed each WFT and WFT+ participant's Fitbit account and recorded minutes of PA and steps per week for twelve weeks.

Data Processing

Data from the ACTs were downloaded and processed using ActiLife Software (Version 6.13.3). The sampling frequency was set to 90 Hz, and the epoch window was 10 s. This sampling frequency was selected based on evidence that multiples of 30 provide more accurate results when using previously created algorithms.[141] Low-frequency extension was not applied as step count is more comparable to criterion measures without it.[141] PA intensity was estimated using the Freedson VM3 algorithm.[58] Step counts were downloaded directly from the devices. Device wear time from the ActiLife software was verified with participant logs. Any days with fewer than 500 minutes (~8.3 hours) of wear time were removed from the analyses.

Data Analysis

We assessed the internal consistency of each subscale of the BREQ-3 and the BPNES by calculating Cronbach's alpha values. Means and standard deviations of the following variables were calculated by group: age, body mass index (BMI), baseline and follow-up ActiGraph wear time, PA motivation subscale values, MVPA minutes and steps per day, per weekday, and per weekend day, and Fitbit assessed PA minutes and steps per week for the two WFT groups. Group (Education, MI, WFT, and WFT+) differences at baseline were examined using one-way ANOVA for all continuous demographic, motivation, and PA outcome variables. Group differences for categorical variables were assessed using chi-square tests. Group differences in

ActiGraph wear time pre-intervention and group differences in ActiGraph wear time post-intervention were examined with one-way ANOVAs. We also assessed differences in post-intervention Fitbit assessed PA variables between the WFT and WFT+ group using t-tests.

We used Cohen's d effect sizes to examine within group changes in each PA motivation and each PA variable in each of the intervention groups. The ranges adopted for small, medium, and large effects were 0.20, 0.50, and 0.80, respectively.[142] Using a series of multiple regression analyses and, when appropriate, Tukey's HSD post-hoc analysis, we investigated between group differences of each outcome variable. We tested two-way interaction effects of group and each motivation variable on each PA outcome variable model. To select covariates for each model, we first tested for a main effect of each potential covariate on each outcome variable. In each case, only baseline values were found to have a significant main effect and, thus, were added to each model as a covariate.

After fitting each model, we examined diagnostic plots to assess linearity, distribution of residuals, and heteroscedasticity. We found that two models had non-normally distributed residuals and significant kurtosis. We also used the Bonferroni Outlier Test[143] to identify data points with large studentized residuals. We determined that one participant in the Education group was a significant outlier in two models (post- intervention intrinsic motivation and autonomy) and, thus, was removed from those analyses, as well as the calculation of group means and standard deviations . After removal, the assumption of normality was met. The significance level was set to $p<.05$ and all analyses were conducted in R version 4.0.2[70]

Results

Data were collected from April 13, 2020 through September 21, 2020. A total of 88 potential participants were screened. Of those, nine did not meet the inclusion criteria, three

declined to participate, and thirty-seven were excluded for other reasons (i.e. they did not respond to communication after having been screened), resulting in the final sample of n=40 (Figure 6). Participants were mostly white, college educated, employed, and overweight (Table 10). There were no significant differences in any demographic characteristic among the groups at baseline. There were also no significant differences in ActiGraph wear time among the groups pre-intervention ($F(3,36)=0.39$, $p=.76$) or post-intervention ($F(3,36)=1.19$, $p=.33$). There were also no significant differences between pre-intervention and post-intervention valid total wear days (5.53±0.75 vs. 5.38±0.93), weekdays (3.73±0.51 vs.3.60±0.60), or weekend days (1.80±0.52 vs. 1.61±0.55).

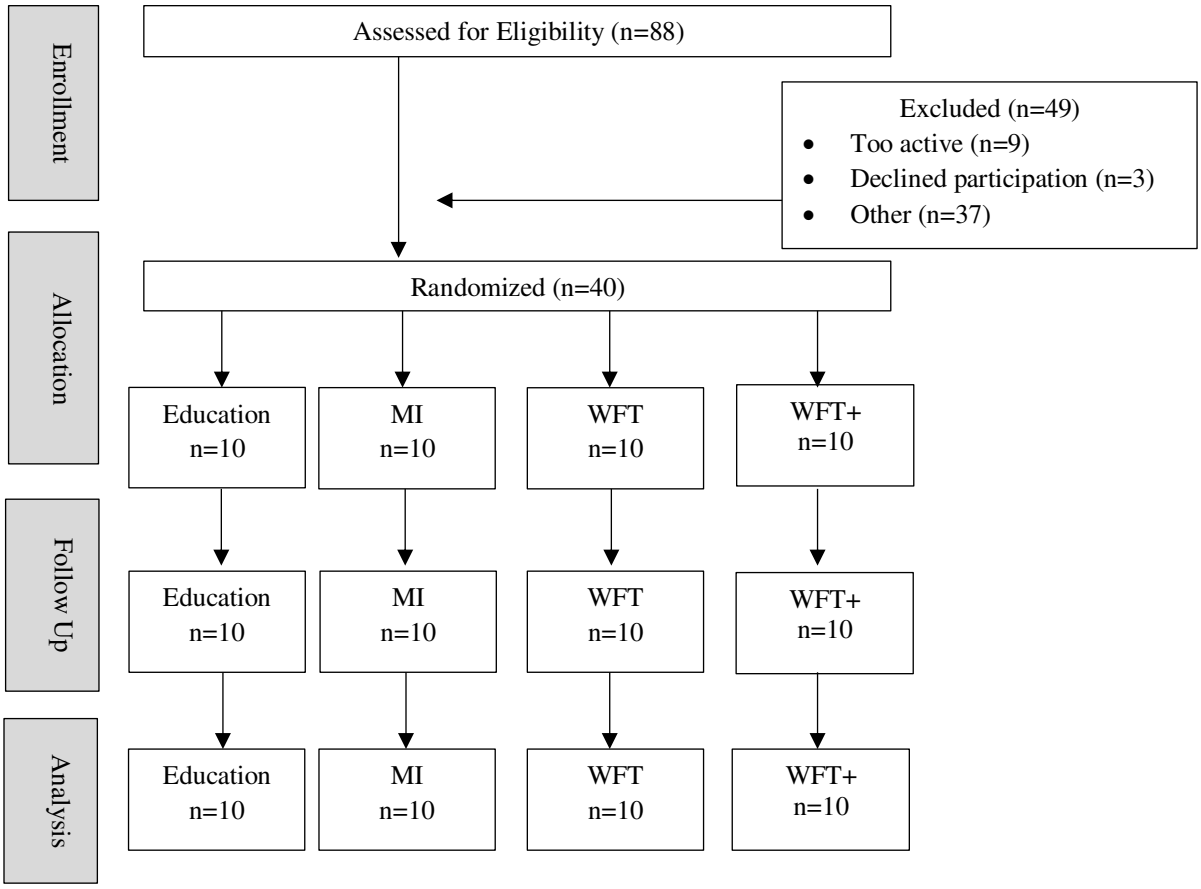


Figure 6. Flow Diagram of Participant Progress Through Phases of Four-Group Randomized Controlled Trial

Table 10. Means and Standard Deviations of Age and Body Mass Index and Counts of Other Baseline Participant Demographic Characteristics and Body Mass Index by Intervention Group

	Group				Group Differences, *p* value
Variable	Education n=10	MI n=10	WFT n=10	WFT+ n=10	
Age	41.8 (12.804)	40.0 (11.265)	42.3 (12.212)	42.4 (10.080)	0.96
BMI	28.89 (6.81)	28.31 (5.01)	25.68 (4.54)	30.53 (7.23)	0.09
Sex					
Females	8	8	8	8	
Males	2	2	2	2	1.00
Education					
High School/ GED	0	0	0	1	
Some College	0	2	0	2	
College Degree	5	1	3	2	
Graduate Degree	5	7	7	7	0.33
Employment					
Full Time	10	9	7	9	
Part Time	0	0	2	1	
Not Working	0	0	2	1	0.40
Race					
White	10	9	10	10	
Other	0	1	0	0	0.38
Ethnicity					
Hispanic or Latino	0	0	0	1	
Non-Hispanic or Latino	8	10	10	8	
Other	1	0	0	1	
Do Not Know/Prefer Not to Answer	1	0	0	0	0.49
Income					
$12,500-$26,999	0	0	1	0	
$27,000-$43,999	1	2	1	0	
$44,000-$59,999	1	0	1	4	
$60,000-$74,999	2	1	2	1	
$75,000-$99,999	2	1	1	0	
$100,000-$150,000	2	5	1	3	
More than $150,000	2	1	2	1	
Do Not Know/Prefer Not to Answer	0	0	1	1	0.45

MI: motivational interviewing; WFT: wearable fitness tracker; WFT+: wearable fitness tracker and MI, BMI: body mass index

Motivation Outcomes

In this analysis, all of the motivation subscales have an alpha above 0.70 (Table 11). A number of interpretations of Cronbach's alpha have been published, differing in their assertion of what constitutes an acceptable alpha.[90]Typically, an acceptable score ranges from 0.70-0.90.

Table 11. Cronbach's Alpha for Internal Consistency of Survey Motivation Subscales

Variable	Alpha (95% CI)
Baseline	
Amotivation	0.71 (0.44,0.86)
External Regulation	0.89 (0.76,0.94)
Introjected Regulation	0.86 (0.76,0.91)
Identified Regulation	0.76 (0.62,0.84)
Integrated Regulation	0.85 (0.73,0.91)
Intrinsic Motivation	0.89 (0.83, 0.93)
Autonomy	0.71 (0.41, 0.83)
Competence	0.77 (0.58, 0.86)
Relatedness	0.90 (0.67,0.97)

There were no significant effects of group on any variable at baseline (Table 12). Over the 12-week intervention, participants in the WFT+ group decreased in amotivation and increased in identified regulation whereas the MI group decreased in external regulation. Both of these groups increased in integrated, and intrinsic motivation, increased in RAI, autonomy, and competence for PA. The Education group also increased in intrinsic motivation. The WFT group increased in competence for PA only.

Table 12. Cohen's d Effect Size Calculations and Confidence Intervals to Assess Within-Group Changes in Motivation Variables and Results of Regression Analyses to Assess Between Group Differences in Motivation Variables After 12-Week Intervention

	Group												
	Education			MI			WFT			WFT+			
Variable	Baseline Mean (sd)	12 Weeks Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline Mean (sd)	12 Weeks Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline Mean (sd)	12 Weeks Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline Mean (sd)	12 Weeks Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	*p* Value
Amotivation	0.48 (0.48)	0.30 (0.40)	-0.40 (-1.01, 0.21)	0.48 (0.46)	0.48 (0.43)	0.00 (-0.72, 0.72)	0.35 (0.41)	0.40 (0.36)	0.13 (-0.40, 0.65)	0.83 (0.31)	0.43 (0.49)	-0.94 (-1.77, -0.11)	.44
External Regulation	1.43 (1.06)	1.58 (1.25)	0.12 (-0.41,0.64)	1.83 (1.04)	1.45 (0.91)	-0.37 (-0.75, -0.001)	0.98 (0.32)	0.89 (0.40)	-0.24 (-1.15, 0.67)	1.53 (0.78)	1.27 (0.73)	-0.34 (-0.86, 0.17)	.44
Introjected Regulation	2.17 (0.82)	2.45 (1.02)	0.30 (-0.57, 1.17)	2.35 (1.07)	2.33 (0.82)	-0.02 (-0.44, 0.39)	2.23 (0.95)	2.31 (0.77)	0.09 (-0.36, 0.53)	2.62 (0.63)	2.48 (0.63)	-0.24 (-0.95, 0.47)	.89
Identified Regulation	3.06 (0.65)	3.10 (0.47)	0.07 (-0.44, 0.57)	2.60 (0.49)	3.10 (0.53)	0.98 (-0.04, 2.00)	3.10 (0.52)	3.20 (0.75)	0.13 (-0.25, 0.52)	2.98 (0.32)	3.33 (0.54)	0.71 (0.09, 1.33)	.41
Integrated Regulation	2.09 (0.57)	2.38 (0.93)	0.34 (-0.31, 1.00)	1.73 (0.51)	2.45 (0.47)	1.48 (0.63, 2.33)	2.50 (0.94)	2.61 (0.81)	0.12 (-0.34, 0.58)	2.03 (0.49)	2.63 (0.83)	0.84 (0.04, 1.63)	.46
Intrinsic Motivation[$]	2.07 (0.73)	2.47 (0.53)	0.57 (0.07, 1.08)	1.98 (0.82)	2.70 (0.62)	0.98 (0.15, 1.81)	2.53 (1.07)	2.87 (0.80)	0.35 (-0.16, 0.86)	1.83 (0.89)	2.98 (0.59)	1.47 (0.47, 2.48)	.09
RAI	3.13 (2.78)	3.37 (2.59)	0.09 (-0.61, 0.79)	1.65 (2.06)	4.00 (2.06)	1.14 (0.39, 1.90)	4.57 (3.03)	5.08 (2.27)	0.18 (-0.30, 0.66)	1.85 (2.16)	4.78 (2.22)	1.33 (0.34, 2.31)	.16
Autonomy[$]	3.60 (0.35)	3.62 (0.72)	(0.04) (-0.65,0.74)	3.28 (0.52)	3.97 (0.43)	1.40 (0.70,2.11)	3.68 (0.56)	4.10 (0.45)	0.79 (-0.18,1.75)	3.63 (0.51)	4.23 (0.35)*	1.34 (0.39,2.29)	**.04**
Competence	3.10 (0.64)	3.20 (0.83)	0.13 (-0.47,0.72)	2.78 (0.48)	3.83 (0.33)*	2.52 (0.79,4.25)	3.03 (1.22)	3.65 (0.97)	0.55 (0.03,1.07)	2.62 (0.73)	3.75 (0.68)*	1.61 (0.52,2.70)	**.02**
Relatedness	3.08 (0.58)	3.06 (1.18)	-0.03 (-0.63,0.57)	3.35 (0.76)	3.92 (0.68)	0.54 (-0.42,1.50)	3.00 (0.37)	3.14 (0.26)	0.27 (-0.03,0.57)	3.30 (0.86)	3.87 (0.67)	0.60 (-0.04,1.28)	.06

Note: MI- Motivational Interviewing, WFT-Wearable Fitness Tracker, WFT+-Wearable Fitness Tracker plus Motivational Interviewing, RAI=Unweighted Relative Autonomy Index

sd=standard deviation, CI= confidence interval

*=Significantly different from Education group, controlling for baseline score, $p<0.05$

$=With one outlier removed

When fitting models to assess differences in post-intervention scores among the four intervention groups, we removed one participant from the Education group from both the intrinsic motivation model and the autonomy model. Bonferonni's Outlier Test[143] indicated both data points had studentized residuals larger than four. Although there were no inconsistencies in this participant's data, we removed it due to the high disproportionate amount of influence it had on these two model outcomes.

No differences among groups were detected post-intervention in any of the BREQ-3 assessed motivation variables. However, we did detect differences among basic psychological needs variables. First, a significant effect of group on autonomy was detected ($F(3,35)=2.80$), $p=.04$, partial $\eta^2=0.20$). The WFT+ group ($p=.04$) had significantly higher scores for autonomy when controlling for baseline scores than the Education group post-intervention. We also detected a significant main effect of group on competence ($F(3,35)=3.72$, $p=.02$, partial $\eta^2=0.15$). Both the WFT+ group ($p=.03$) and the MI group ($p=.03$) had significantly higher post-intervention scores when controlling for baseline scores in comparison to the Education group. No other between group differences were detected.

Physical Activity Outcomes

There were no group differences in any PA variable at baseline (Table 13). Our Cohen's d effect size and confidence interval calculations and showed no significant within-group changes for MVPA minutes or steps per day, weekday, or weekend day. We also found no main significant effect of group when controlling for baseline values (p from 0.54 to .90).

Table 13. Cohen's d Effect Size Calculations and Confidence Intervals to Assess Within-Group Changes in Motivation Variables and Results of Regression Analyses to Assess Between Group Differences in Physical Activity Variables After 12-Week Intervention

	Group												
	Education			MI			WFT			WFT+			
Variable	Baseline, Mean (sd)	12 Weeks Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline, Mean (sd)	12 Weeks, Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline, Mean (sd)	12 Weeks, Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	Baseline, Mean (sd)	12 Weeks, Mean (sd)	Baseline vs. 12 Weeks Cohen's d (95% CI)	*P* Value
MVPA													
Min. per Day	65.37 (19.82)	66.70 (17.83)	0.07 (-0.36,0.50)	56.26 (25.10)	67.75 (16.47)	0.53 (-0.35,1.42)	74.05 (23.58)	76.37 (29.19)	0.09 (-0.53,0.71)	53.82 (20.88)	71.08 (36.90)	0.49 (-0.03,1.00)	.70
Min. per Weekday	62.55 (22.43)	66.17 (16.99)	0.17 (-0.35, 0.70)	51.63 (26.84)	64.00 (25.10)	0.48 (-0.49,1.44)	74.18 (32.55)	78.97 (32.67)	0.15 (-0.36, 0.66)	51.90 (22.18)	68.60 (41.11)	0.44 (-0.12,1.01)	.90
Min. per Weekend Day	73.25 (30.61)	72.32 (29.27)	-0.03 (-0.92, 0.86)	69.16 (38.20)	69.70 (22.30)	0.02 (-0.74 ,0.78)	70.58 (18.33)	66.17 (38.63)	-0.14 (-0.90, 0.62)	63.87 (27.17)	76.38 (38.50)	0.37 (-0.43,1.17)	.87
Steps													
Steps per Day	5690.71 (1974.24)	6155.58 (1370.35)	0.24 (-0.16,0.63)	4640.30 (1759.94)	5400.56 (1314.90)	0.48 (-0.31, 1.28)	5817.82 (2334.36)	6693.01 (2394.24)	0.37 (-0.39,1.13)	5564.56 (1783.55)	6232.15 (2857.27)	0.26 (-0.32,0.83)	.88
Steps per Weekday	5322.45 (2101.10)	6216.31 (1511.65)	0.47 (-0.12, 1.04)	4514.95 (2646.50)	5211.16 (1847.80)	0.31 (-0.59,1.20)	5877.11 (2741.19)	7183.81 (2470.83)	0.50 (-0.26, 1.26)	5346.10 (1712.86)	6123.24 (3047.30)	0.24 (-0.43,0.91)	.54
Steps per Weekend Day	6449.33 (3056.45)	6387.75 (2350.78)	0.01 (-1.06,1.08)	5293.85 (2554.75)	5235.22 (1749.21)	0.03 (-0.54, 0.60)	5494.35 (2142.58)	5275.90 (3293.88)	-0.08 (-0.76, 0.61)	6189.68 (2784.17)	6565.06 (3156.44)	0.30 (-0.36,0.96)	.83

Note: MI- Motivational Interviewing, WFT-Wearable Fitness Tracker, WFT+-Wearable Fitness Tracker plus Motivational Interviewing, sd=standard deviation, CI= confidence interval, MVPA=Moderate to Vigorous Physical Activity, Min.=Minutes

Whereas we did not find evidence of a group effect on PA over twelve weeks, we did identify an effect of baseline minutes of PA on change in PA from pre-to post-intervention. We found that in the overall sample of participants, participants with lower baseline minutes of PA showed more improvement in minutes of MVPA over twelve weeks (β=-0.39, p=.009).

We detected a significant interaction effect of group and baseline RAI on post-intervention steps per day ($F(3,31)=2.94$, $p<.05$, partial $\eta^2=0.31$). Post hoc analysis revealed that the WFT+ group had significantly more steps per day post-intervention per unit of increase in baseline RAI than the WFT group ($p<.01$) (Figure 7B).

Examining the results of the RAI by group interaction analyses, we determined that there was a notable change within one group on the effect of baseline RAI from pre- to post-intervention. Specifically, at baseline, RAI significantly predicted baseline steps per day in the WFT group (β=538.12, $t(32)=2.63$, p=.01) (Figure 7A). Baseline RAI also significantly predicted post-intervention steps per day in the WFT group, but the association was negative (β=-425.94, $t(32)=-2.21$, p=.03) (Figure 7B). Importantly, baseline RAI score also predicted post-intervention RAI score in this group (β=0.56, $t(32)=2.51$, p=.02) (Figure 7C). Simply stated, higher baseline RAI scores predicted higher baseline steps and higher post-intervention RAI scores but lower post-intervention steps in this group.

In contrast, in the WFT+ group, baseline RAI did not significantly predict baseline steps per day (β=-41.35, $t(32)=-0.144$, p=.89) (Figure 2A), nor post-intervention RAI score (β=0.43, $t(32)=1.37$, p=.18) (Figure 7C). However both baseline (β=730.10, $t(32)=2.97$, p=.006) (Figure 2B) and post-intervention RAI scores RAI scores predicted post-intervention steps per day (β=698.14, $t(32)=2.72$, p=.01) (Figure 7D).

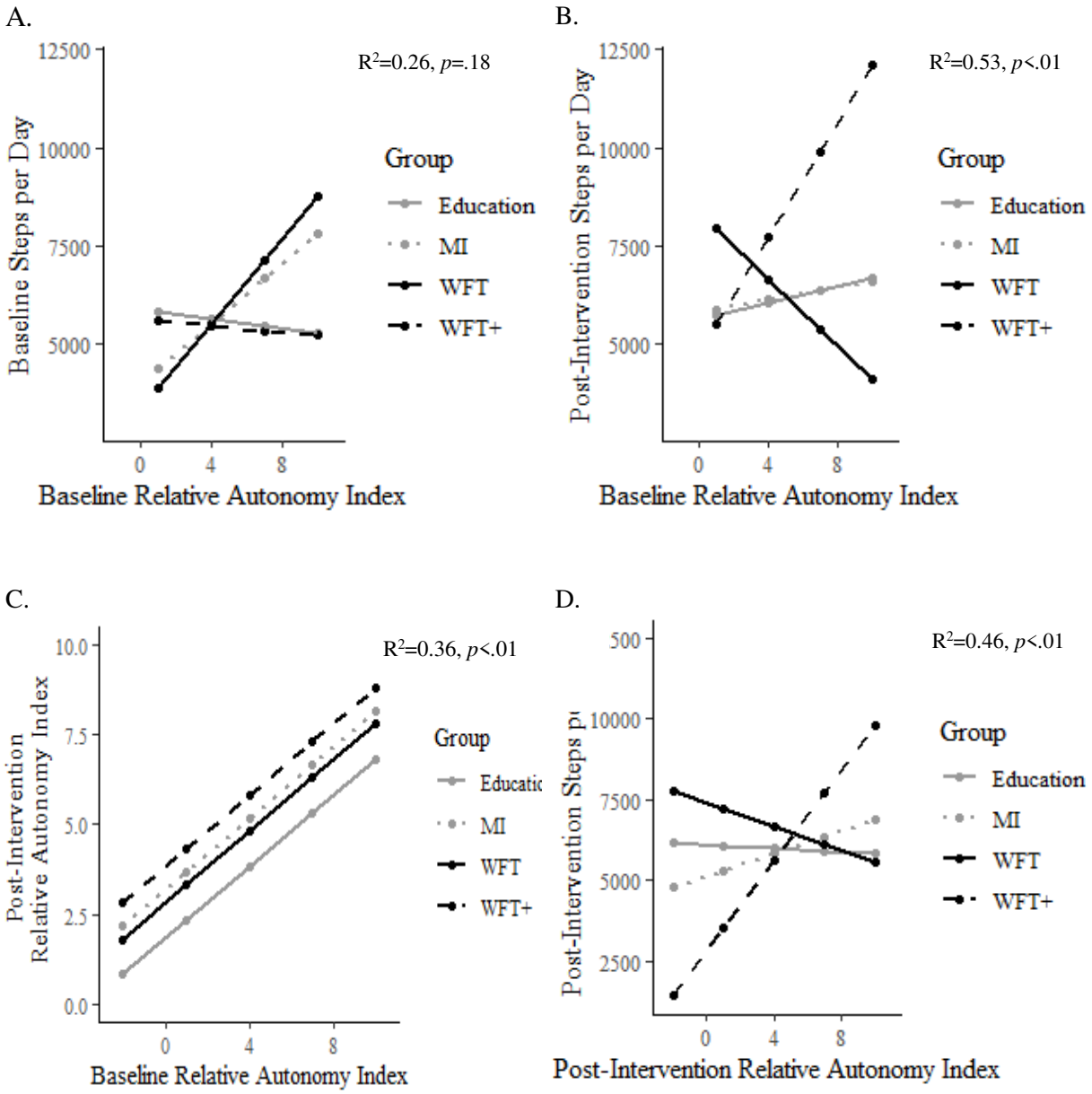
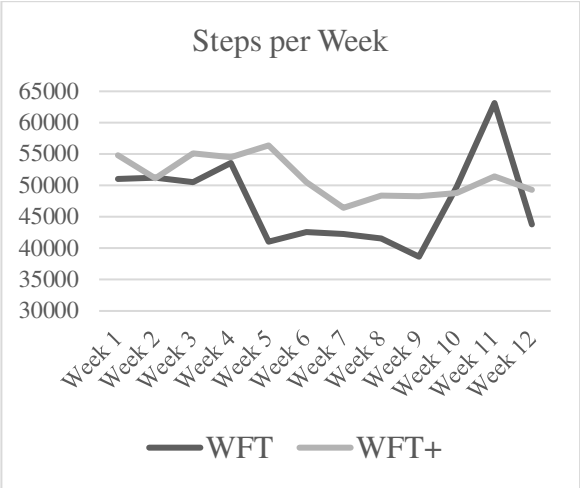


Figure 7. Relative Autonomy Index and Steps per Day Pre- and Post-Intervention

Figure 8 and Table 14 show Fitbit assessed weekly PA minutes and steps per week for the WFT and WFT+ groups. Table 15 also shows the results of t-tests comparing the two. There were no significant differences between groups in PA minutes nor steps at any week.



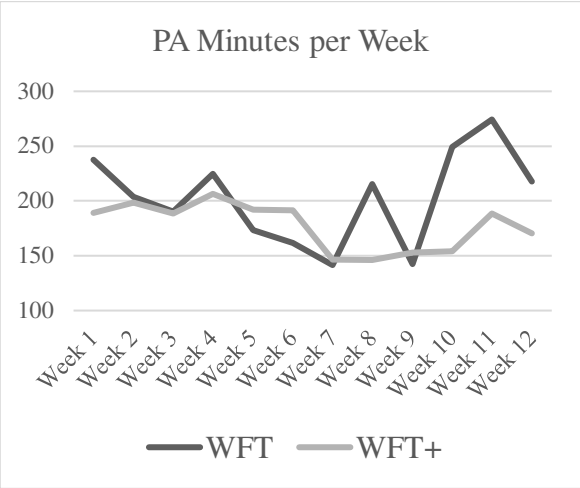


Figure 8. Steps and Physical Activity Minutes per Week Assessed by the Fitbit Inspire

Table 14. Group Comparison of Steps and PA Minutes per Week Assessed by the Fitbit Inspire

Steps per Week			
	WFT Mean (sd)	WFT+ Mean (sd)	Difference
Week 1	51055.60 (35543.61)	54777.44 (14187.52)	p=.77
Week 2	51285.80 (16823.88)	51147.33 (20820.18)	p=.99
Week 3	50505.80 (24724.44)	55118.22 (22712.89)	p=.68
Week 4	53606.00 (28728.08)	54469.67 (21296.16)	p=.94
Week 5	41007.70 (26101.07)	56377.78 (25112.76)	p=.21
Week 6	42590.50 (25346.04)	50488.78 (30383.52)	p=.55
Week 7	42282.70 (26998.35)	46438.33 (26998.35)	p=.75
Week 8	41589.00 (22783.78)	48383.11 (27411.53)	p=.56
Week 9	38646.8 (19303.05)	48306.0 (28367.91)	p=.39
Week 10	49785.80 (36720.15)	48778.11 (29065.05)	p=.95
Week 11	63134.70 (36515.74)	51409.44 (33487.00)	p=.48
Week 12	43827.6 (37789.51)	49315.0 (30506.75)	p=.73
			PA Minutes per Week
	WFT Mean (sd)	WFT+ Mean (sd)	Difference
Week 1	237.50 (240.27)	189.11 (70.51)	p=.57
Week 2	203.60 (80.41)	198.66 (124.61)	p=.92
Week 3	190.00 (159.37)	188.56 (134.61)	p=.98
Week 4	225.00 (150.63)	206.44 (115.15)	p=.77
Week 5	173.60 (170.24)	192.00 (155.77)	p=.81
Week 6	161.40 (145.76)	191.56 (147.95)	p=.66
Week 7	141.50 (152.71)	146.56 (128.11)	p=.93
Week 8	215.20 (129.15)	146.11 (123.27)	p=.25
Week 9	142.40 (102.26)	152.67 (128.87)	p=.85
Week 10	249.20 (221.06)	154.33 (119.60)	p=.27
Week 11	274.30 (232.72)	188.67 (177.76)	p=.38
Week 12	217.70 (223.82)	170.67 (188.08)	p=.63

Note: sd=standard deviation

Discussion

Motivation Outcomes

In this study, we assessed motivation for PA as described by the SDT and PA behavior in four groups, each assigned a different condition over a twelve-week intervention. The WFT+ and MI group had reductions in amotivation and external regulation, respectively. The WFT+ group also had an increase in identified regulation and both the WFT+ and MI group had increases in integrated regulation, intrinsic motivation, RAI, and the basic psychological needs of autonomy and competence. In addition, the Education group had an increase in intrinsic motivation whereas the WFT group increased in competence for PA. When comparing groups, the WFT+ group had a significantly higher level of autonomy than the Education group after 12 weeks. Both the WFT+ and MI group had significantly higher levels of competence than the Education group at the end of the intervention.

These improvements in the basic needs of autonomy, competence, and autonomous forms of regulation is not surprising given that, while not intentionally designed to do so, the tenants of MI likely impact PA motivation. For example, the first principle of MI empathetic listening. Using this skills, the practitioner can support the client's need for relatedness by helping her to feel accepted.[21] Practitioners can support the client's need for autonomy by exploring and understanding the patient's motivations for and ambivalence toward change, another technique central to MI.[21] Competence is enhanced when the practitioner empowers the client to make decisions and take action for change thus improving the client's self-confidence in her own capacity for change.[21]

A number of empirical studies have evidenced the positive association of MI interventions with improvements in self-determined motivation for PA. MI is associated with

improvements in basic psychological needs and autonomous forms of motivation in sedentary adult women,[40] adults in a worksite wellness program,[46] adults receiving MI through a web-based intervention,[50] and adults in a group exercise class.[13] MI is also related to reductions in controlled forms of regulation,[45] and amotivation.[48]

To see no changes in SDT subtypes in the WFT groups was remarkable. Longitudinal studies of PA engagement indicate that new exercisers increase in identified regulation and intrinsic motivation within twelve weeks of exercise initation.[144] We see this phenomenon in the Education group that had a significant within-group increase in intrinsic motivation over the course of the intervention.

On the other hand, other studies with WFTs that measured motivation using the SDT constructs indicate that WFTs may negatively impact self-determined motivation for PA. In one sample of adults using WFTs, identified regulation decreased significantly after six weeks of use; however, this group also increased hours per week of physical activity.[145] Similarly, 8 weeks of Fitbit use in adolescents was associated with a significant increase in amotivation and external regulation, and a significant decrease in autonomy, competence, and autonomous motivation (mean scores of identified regulation and intrinsic motivation combined).[37] Similarly, in separate sample of adolescents, five days of Fitbit use was associated with increased amotivation and decreased autonomous motivation, although these differences were non-significant.[146]

According to Etkin,[147] external rewards for a behavior can undermine intrinsic motivation, making that behavior feel like work, instead of fun. Furthermore, in the absence of tangible external rewards, simply measuring a behavior can have the same outcome. For example, a sample of young adults who chose to wear a pedometer while walking reported significantly less enjoyment post-walk but also walked significantly more than the comparison

group. Importantly, amount of walking was not correlated to enjoyment, nor did it mediate the association between measurement and enjoyment.[147] In a follow-up study, participants were either instructed to look at their pedometer or were told that looking was optional. Again, when compared to a comparison group, both experimental groups walked more, but reported significantly less enjoyment.[147]

In the current study, the WFT group is the only group that did not experience an increase in any subtype of autonomous motivation. We speculate that activity measurement thwarted meaningful growth in autonomous motivation. In contrast, the WFT+ group measured their activity but also benefitted from the principles of MI, and significantly increased their autonomous motivation. Thus, we believed that the positive effects of MI counteracted the detrimental effects of activity measurement on intrinsic motivation for PA.

Physical Activity Outcomes

We detected no within-group changes in MVPA minutes or steps per week, weekday, or weekend day from pre- to post-intervention. We also detected no between-group differences in these metrics pre- or post-intervention. These findings are consistent with a previous study in which Ellingson and colleagues[136] also compared WFT and WFT combined with MI and found no significant within-group changes, nor between-group differences after a twelve-week intervention. Further, this Ellingson, et al.[136] determined that irrespective of group assignment, participants with the lower amounts of baseline MVPA minutes per day had the larger improvements at the conclusion of their study (β=-0.49, $p<0.01$),[136] a phenomenon that was repeated in the current study. These results suggest that participation in a PA intervention study is sufficient to influence improvements in MVPA in participants with the lowest baseline levels.

Adding a layer of complexity to these results, this study was conducted in its entirety during the Covid-19 pandemic. In general, the spread of Covid-19 and stay-at-home orders have been associated with worldwide reductions in objectively measured daily steps,[148,149] and self-reported PA compared to pre-pandemic levels.[150,151] In Thailand, exposure to a nationwide physical activity intervention that was released in the initial days of the country's Covid-19 restrictions was associated with significantly higher odds of meeting PA recommendations compared to non-exposed citizens.[151] In another study of health behaviors conducted during the early months of the pandemic, a PA intervention was associated with a significant increase in minutes of MVPA per week whereas the control condition was associated with a significant reduction.[152] Potentially, simply participating in a PA intervention or study may be an adequate stimulus to maintain levels of PA engagement in a time when otherwise, PA levels have decreased across the globe.

To further probe the effects of the current study on MVPA and steps, we examined interaction effects of intervention group and a number of motivation and demographic variables. We discovered a significant interaction effect of baseline RAI and group on steps per day. At baseline, participants in the WFT group with the highest RAI score also had the highest number of steps per day. This is an expected relationship as autonomous motivation, specifically identified regulation, is associated with PA initiation and intrinsic motivation is associated with persistence.[8] Unexpectedly, after twelve weeks of WFT use, this relationship reversed in that participants who had the lowest RAI scores at baseline had the highest number of daily steps post-intervention. Importantly, we did not detect a significant change in RAI scores across time, so participants with the lowest RAI scores at baseline continued to have the lowest scores post-intervention.

We interpret these findings to mean that the addition of a WFT in participants with more controlled motivation for PA can drive PA behavior change. According to a meta-analysis by Ng and colleagues,[153] controlled motivation, and particularly introjected regulation, can predict PA engagement. However, it is also associated with increased anxiety and disappointment, and its effects may only last a short time.[153] Also, Attig and collegaues[106] determined that controlled forms of motivation for PA, when combined with a WFT can result in what they term the dependency effect. When WFT users find less value in PA that is performed when they do not have the WFT (i.e. they forgot it or the battery has died), this is the dependency effect. Higher levels of controlled motivation for PA are significantly positively associated with the dependency effect whereas high levels of autonomous motivation are significantly negatively associated with it.[106] Harrison and colleagues[154] describe WFT users who chose activities that could be tracked, for example running instead of yoga. We interpret this as a version of the dependency effect if, in this case, the user did not have intrinsic motivation for running.

In contrast, we detected a significant interaction effect of baseline RAI and group on steps per day in the WFT+ group but the associations were different than those in the WFT group. Like the WFT group, at baseline high RAI scores predicted high steps per day. Post-intervention, this association remained whereas in the WFT group, high RAI scores predicted low steps. The difference in these two group may lie in the distinction between intention and behavior. Hagger and colleagues[155] found that the association between autonomous motivation and PA engagement was significantly mediated by intention for PA. Rodrigues and colleagues[156] modeled the same mediation relationship and also found that intention only explained 11% of the variance in exercise persistence. Taken together, we speculate that in both the WFT and WFT+

group participants with high RAI scores likely had significant intention to participate in PA. However, as Rodrigues and colleagues[156] point out, intention is not sufficient to predict behavior.

We suspect that the addition of MI to the WFT+ group facilitated the creation of action and coping plans, bridging the gap between intention and behavior in participants with elevated autonomous motivation for PA. A meta-analysis by Belanger-Gravel and colleagues[157] and a second by Carraro and Gaudreau[158] suggest that or a mix of action planning and coping planning mediates the relationship between intention and behavior. An action plan outlines specific details of where, when, and how the behavior will take place whereas coping plan details how the participant will overcome barriers and obstacles. According to Miller and Rollnick,[159] planning is a core process in MI. After developing a trusting relationship, the client can begin to voice her own reasons for change, leading to an action plan that is derived by the client and practitioner in collaboration. The role of the practitioner is to support the client in the identification of resources and the establishment of metrics to assess if the plan is effective and appropriate. A systematic review contends that the MI practitioner-client relationship is associated with more complete actions plans, which predicted physical activity behavior,[160] A smaller, but still significant association between MI and coping planning was decribed.[160]. Unfortunately, we did not measure these planning variables and suggest they be included in any subsequent studies.

We examined the weekly steps and minutes of PA as assessed by the Fitbit in the WFT and the WFT+ group. We detected no significant differences between groups at any week, nor did we detect a significant decline in PA or steps from the beginning to the end of the intervention, as has been seen in other studies.[136] Unfortunately, we did not collect participant reports of Fitbit wear, nor did we have access to these data via platforms using the Fitbit API, like Fitabase (Small Steps Inc., San Diego, CA). Therefore, whereas there were no differences in

PA or steps, we cannot say with confidence that these metrics are within the context of consistent Fitbit wear between groups.

Limitations

We acknowledge that this study has limitations. First, we chose to conduct the entire study during the Covid-19 pandemic. Therefore, we recognize that comparisons with related studies may be limited. Second, our sample was also quite homogenous, consisting of apparently healthy, majority white, highly educated, employed, and overweight participants from the same region of the country, which may limit generalizability of the findings. Furthermore, despite have a sufficient sample for statistical power, the sample was small. We recommend future studies recruit a larger, more diverse sample to examine these conditions more thoroughly. Third, we did not assess wear time or compliance with wear directives of the Fitbit in the WFT and WFT+ groups. We were able to assess differences in Fitbit assessed PA metrics, and recognize that these are not synonymous. We recommend that these data be collected via self-report or technological methods, like Fitabase, to clarify if group differences are associated with device wear or use. Fourth, whereas we agree that RAI is an appropriate estimation of motivational quality,[92] we also recognize that some recent research has evidenced that elevated levels of both introjected regulation, and more autonomous forms are predictive of PA engagement.[102,161,162] RAI does not allow for an investigation into the more nuanced and multidimensional aspects of SDT motivation as it pertains to PA. A technique like latent profile analysis would permit investigators to examine the intricacies of motivation and PA but this sample was underpowered for such models.

Conclusions

We have concluded that twelve-weeks of bi-weekly MI sessions, either in combination with a WFT or alone, is associated with increases in the basic psychological needs of autonomy and competence and in autonomous forms of motivation for PA. MI alone or in combination with a WFT is also related to reductions in controlled forms of motivation. We recommend other researchers investigate a potential mediation effect between autonomy and competence and the more autonomous forms of motivation as the sample size in the current study was prohibitive. Also, we determined that using a WFT for twelve weeks unexpectedly did not impact any subtype of SDT motivation. We suspect that the measurement of PA by the WFT hindered autonomous motivation growth.

We've also concluded that none of the intervention groups significantly affected MVPA or steps over the 12 weeks, either within or between groups. We determined that, regardless of group, the participants with the lowest baseline minutes of MVPA improved the most during the study period. Also, overall PA levels were maintained during a time when, globally, PA was declining. Therefore, we speculate that participation in a PA study may be sufficient to improve PA in the least active adults and maintain PA in already active participants during a global pandemic.

Finally, we determined that the association between RAI and steps per day differed between the WFT and WFT+ group. WFT participants with high RAI at baseline had high steps per day at baseline but low steps per day post-intervention. WFT+ participants with high RAI at baseline had high steps per day at baseline and post-intervention. Motivation and behavior are likely mediated by both intention and planning, both of which are improved with MI. We suggest that future studies include assessments of both intention for PA and PA planning. Conversely,

participants with low RAI at baseline in the WFT group had high steps per day post-intervention. We conclude that improvement in PA among participants with low baseline RAI in the WFT group was driven by more controlled forms of motivation, which has also been linked to a phenomenon called the dependency effect. As such, we recommend researchers measure the dependency effect in future studies.

In summary, WFTs alone are impactful in improving PA in people with high levels of controlled motivation. However, we do not predict that these individuals will persist in that behavior beyond the conclusion of the intervention. On the other hand, MI alone and a WFT combined with MI both support improvements in autonomous motivation, but not short-term PA. To explore the effects of improvements of autonomous motivation on PA over time, we recommend researchers employ a longitudinal study design. Generally speaking, additional research is required to examine the benefits of WFTs, MI, or the two combined on long-term motivation for PA and PA behavior.

CHAPTER 6: OVERALL CONCLUSIONS

Summary of Studies

Due to the widespread popularity of wearable fitness trackers (WFTs) for PA, it is imperative that researchers, health and fitness professionals, and consumers understand the impact, if any, they have on motivation and engagement. The paradox between the large number of devices sold each year[4] and the high rate of device abandonment[5] suggests that whereas the devices may be useful for some, they are not useful for all. In this series of studies, I sought to gain insight into WFTs, their effects, for whom are they effective, and how they might be better leveraged to influence PA.

In the first study, a systematic review, I examined literature from 2008 to 2018 that assessed the use of WFTs in PA intervention studies. Interventions that combine behavior change techniques are more effective than techniques used in isolation.[14] As such, I also investigated the impact of a widely used health behavior change intervention, motivational interviewing (MI), combined with WFTs, and on its own. The Self Determination Theory of motivation served as the theoretical framework for this and all subsequent studies. This study revealed that WFTs impact PA in the least active adults but also seemed to positively impact self-reported motivation for PA. The findings confirmed that MI is an effective intervention, influencing both PA and motivation for PA. At the time of this study, only two recently published manuscripts combining WFTs and MI were found in the literature. Both suggested that the combination could support increases in PA in adults, but neither study assessed motivation.

In my second study, I conducted an accuracy assessment of a novel WFT, the Shyft STYR. This device estimates steps taken per day and daily energy expenditure. It's hardware seemed comparable to a Fitbit,[16] although I was unable to confirm this due to limited information made available by the device manufacturer. In a free-living study comparing the STYR estimated metrics to those of an ActiGraph GT3X+, I determined that the STYR grossly overestimated both daily steps and energy expenditure. In research, the utility of the device lies in its accuracy[57] and inaccurate device metrics may influence study results in unintended ways. For example, if a WFT is used as an intervention to increase PA, an overestimation of daily steps by the WFT may result in an overall reduction in PA. Whereas there are currently no commercial WFTs on the market with perfect or near-perfect step or energy-expenditure accuracy, I chose to use a well-known and widely studied WFT, a Fitbit, in my randomized controlled trial.

In my third study, I conducted a mixed-methods examination of motivation for PA and PA engagement in current and former WFT users. The results of this study revealed no differences in PA between groups, but did reveal that current WFT users have significantly higher levels of both introjected and integrated regulation for PA. These results align with the work of Friel and Garber[102] who assessed PA motivation in WFT users using latent profile analysis. In their work, a motivational profile with both high introjected and high autonomous motivation had higher proportions of WFT users and physically active participants than other clusters.

In my study, qualitative data revealed that current users valued their WFT as a means to collect data about their PA whereas former users had concerns about data accuracy and did not perceive that their WFT impacted their PA significantly. Former users also felt stressed when they received feedback from their WFT about not meeting their WFT goals. Feedback has the

potential to both support and thwart autonomous motivation, depending on how the user interprets that feedback.[105] Attig and Franke[106] identified a number of traits that seemed to protect a WFT user from perceiving feedback as negative. These traits include having an autonomy causality orientation, the capacity for dialectical thinking, affinity for technology interaction, and the need for cognitive closure.

The final study in this series tested the effects of WFT, MI, the combination of both (WFT+), and PA education on PA and motivation over the course of twelve weeks. I found that both MI and the WFT+ conditions were associated with increases in autonomy, competence, and autonomous forms of motivation. The WFT group only increased in competence and the Education group increased in intrinsic motivation. There were no significant effects of the interventions on minutes of MVPA or steps per day.

I did find that participants in the WFT group with low baseline relative autonomy index score had low steps per week pre-intervention but high steps per day post-intervention. In contrast, participants in the WFT+ group with low relative autonomy index score pre-intervention had low steps per day both pre- and post-intervention. I speculate, then, that autonomous motivation is not sufficient, on its own, to drive PA, as seen in the WFT group. I also speculate that the addition of MI in the WFT+ group was effective in maintaining the association between autonomous motivation and PA. Other researchers have determined that motivation does not predict behavior, but rather intention, and planning bridges the gap between planning and behavior.[156-158] Since planning is a central construct in MI,[159] it is possible that participants in the WFT+ group intended to engage in PA and took steps to plan for those sessions.

Future Directions

Studies three and four, taken together, led me to consider whether there is an ideal person for whom WFTs might be the most effective for both autonomous motivation and persistent PA engagement. In investigating this question, I discovered the work of Vallerand[163] who expanded upon the Self Determination Theory (SDT) and devised a hierarchical model of SDT motivation. In this model, humans have a global motivational disposition (intrinsic, extrinsic, or amotivated) that guides their choices and behaviors. This global disposition, or personality, is influenced by global factors, like age, work status, and living situation. For example, Vallerand[163]gives the example of an elderly person who moves into an assisted living home. This person's global orientation may shift toward more controlled forms of motivation due to being reliant on staff for taking care of basic needs like food and hygiene. The impact of those factors, however, is mediated by how they influence the person's perception of their general autonomy, competence, and relatedness. So, if an elderly person does not perceive the assistance by care staff to thwart her autonomy, competence, or relatedness, she may not experience a change in global motivation. The global motivational disposition both influences and is influenced by the second level, the contextual level, in which humans are motivated in reference to a specific context like work, leisure, school, and more. Similarly, the contextual level influences and is influenced by the situational level, which pertains to specific instances or events within the particular context.

Like the global level, both the contextual level and situational level are influenced by different types of factors and the effects of those factors are mediated by the three basic psychological needs. At the contextual level, influential factors are those that persist in that context, like a specific teacher in an educational context, a coach in a PA context, or a supervisor or work culture in a work context. At the situational level, influential factors are those that are

present only in that specific situation. For example, having an injury or trying a new exercise program for the first time are not permanent, situational factors.[163]

According to Vallerand[163], the influence of the global levels flows down, the influence of the contextual level flows up and down, and the influence of the situational level flows up. For example, if a woman attends an exercise class (situational) and finds that it supports her psychological needs of autonomy, competence, and relatedness, she may not only feel more autonomously motivated for her next exercise class (situational) but also for PA in general (contextual) and overall (global). Contextual motivation also predicts future intentions to engage in the contextual behavior.[163-166]This hierarchical model has been tested specifically in PA research.[164,165,167]

Using this model as a framework, I devised a working hypothetical model of how WFTs influence both motivation and PA engagement. This model also takes from the work of: Guertin and colleagues,[168] Lavigne and Vallerand,[166] Attig and Franke,[106,169] Rodrigues and colleagues,[156] Rockmann,[170] Cherubini and colleagues,[171] Cuevas-Campos and colleagues,[172] and Asimakopoulos and colleagues.[173] Figure 9 depicts the overall model.

Hypothetical Model of Wearable Fitness Tracker Effect on Motivation and PA

Taking the hierarchical model of Vallerand,[163] I first added a component of SDT not examined elsewhere in this set of studies: **relative goal content.**[174] Goals can either fulfill or thwart basic psychological needs, depending on if they are intrinsic or extrinsic. Intrinsic goals are inherently satisfying and for PA these goals pertain to improving one's health or becoming more fit.[174] Extrinsic goals in the context of PA include the pursuit of PA to become more physically attractive to others.[174] In a study by Sebire and colleagues,[167] intrinsic goals significantly predicted autonomous motivation for PA, which significantly predicted MVPA.

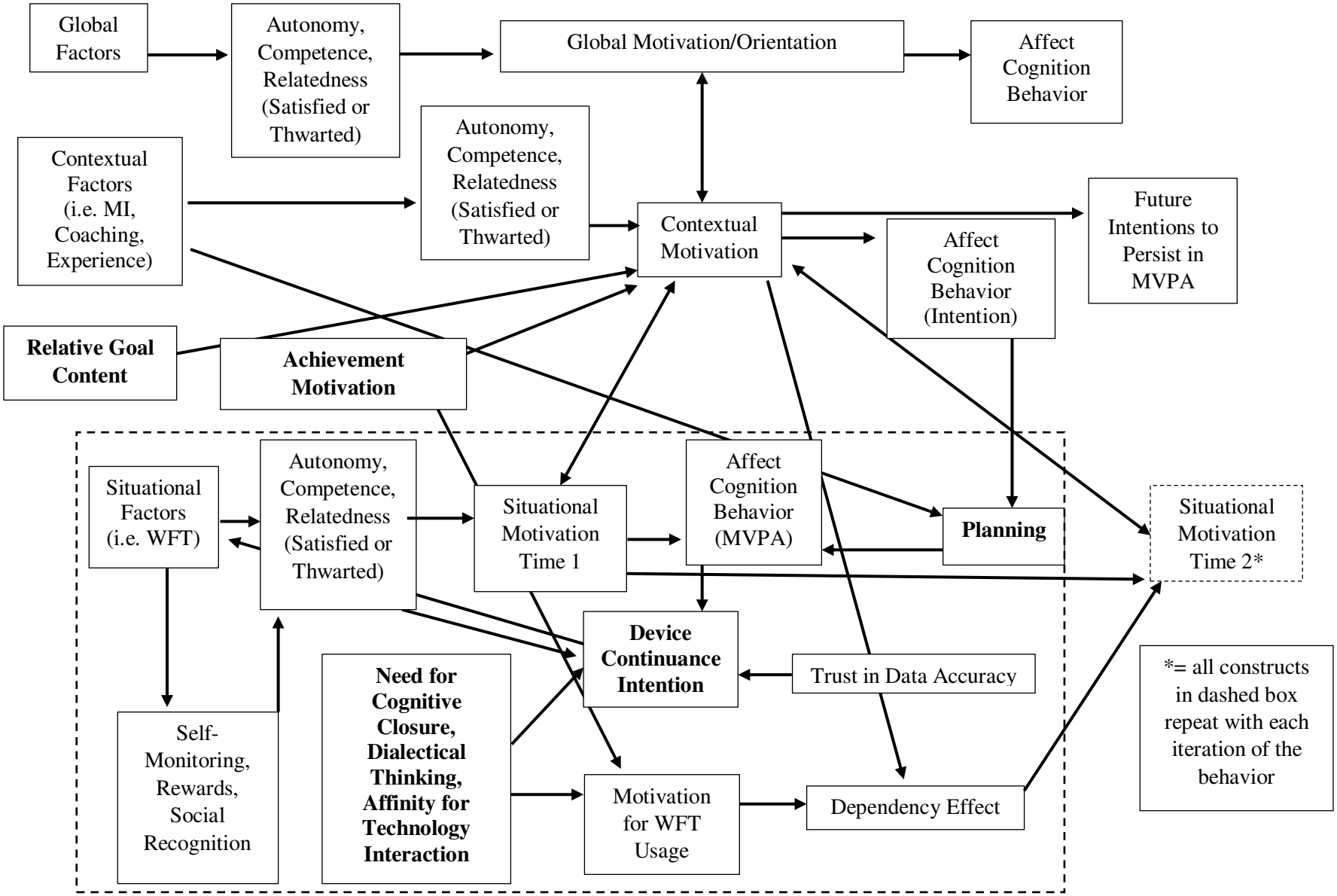


Figure 9. Hypothetical Model of WFT Effect on Motivation and PA[114,156,166,168-173]

I also included **achievement motivation** to the hypothesized model, which was also not examined in this series of studies. Whereas not associated with SDT, according to Atkinson,[175] achievement motivation predicts whether a person will approach or avoid a situation based on the probability of success or failure. Specifically, approach tendency is an achievement motivation guided by hope for success whereas avoidance tendency is guided by fear of failure. Attig and Franke[106] determined that approach tendency is significantly associated with constructs that predict persistent WFT use; specifically, autonomous motivation for PA and autonomous motivation for WFT use.

As mentioned in study four, it is likely that planning mediates the association between motivation for PA and PA behavior, albeit planning is not a construct in SDT.[157,158] Based on the results of study four that indicate that autonomous motivation is not sufficient on its own to drive PA, I determined that **planning** must be included in the model.

I added a fourth construct to the model: **WFT device continuance intention**. According to Rockman,[170] when the features of a digital health mobile application, like the ability to track progress (self-monitoring), earn rewards, and earn social recognition are perceived to fulfill the psychological need of competence, intention to continue using the application is also predicted. This concept has not yet been tested directly in WFTs, although the features of mobile application and WFTs are often similar if not the same. Attig and Franke[169] also determined that trust in the accuracy of WFT estimated data also predicts the intention to continue device use. I also discovered this in study three, thereby determining it should be added to the hypothetical model.

The remaining constructs in the hypothetical model are taken from the work of Attig and Franke[106,169] As mentioned in study three, these researchers determined that specific personal

traits like need for **cognitive closure, dialectical thinking, and affinity for technology interaction** significantly predict intrinsic motivation for WFT, which also predicts intention to continue using the WFT. These researchers also discuss the dependency effect, or the tendency to only engage in PA when the device is also in use. Extrinsic motivation for both WFT use and for PA significantly predicts the dependency effect. I speculate, then, that since PA engagement is likely to diminish when the WFT is not available, future situational motivation for PA may be impacted, depending on the availability of the device.

Importantly, pieces of this model have been tested in isolation. However, to better understand the influence of WFTs on motivation and behavior, future researchers may benefit from designing an RCT, like study four, but employ a longitudinal design. Researchers should also assess global, contextual, and situational motivation, relative goal content, achievement motivation, planning, intentions to persist in future PA behavior, traits like need for cognitive closure, dependency effect, motivation for WFT usage, intention for WFT use continuance, and trust in estimated data accuracy. Each of these factors directly or indirectly influence the impact of WFTs on motivation and PA.

Suggestions for Wearable Fitness Trackers Improvements

The American College of Sports Medicine announced that wearable technology will continue to be a top trend in PA and fitness in 2021.[176] Therefore, it remains likely that both sales and abandonment will remain high. In order for WFTs to better fit more users, a number of researchers have provided suggestions regarding device modifications.

First, in order to support, not thwart basic needs, feedback from the device should a) be specific to the person, b) providing information that helps the user connect their performance with outcomes, and c) provides the next challenge to push their work further.[168,171,177] The

delivery of feedback should also be altered. If feedback becomes repetitive or predictable, the user may experience it as controlling. It may be more effective if feedback is delivered when the user performs the activity at a novel time, for example.[171,177]

WFT platforms should also reconsider how and if rewards are given to users. Rewards should celebrate the user's competencies. For example, non-monetary rewards such as digital badges given when the user attains a certain specific goal or achieves sustained performance over time may support autonomous motivation for PA.[177]

Finally, WFT devices should provide optimal challenge for the users. Very few devices tailor interventions or goals to the specific characteristics of the user.[177] For example, a user who typically walks 8,000 steps per day prior to WFT acquisition may perceive a goal of 10,000 steps to be challenging but possible. On the other hand, a person who walks 4000 steps per day prior to device acquisition may find 10,000 steps to be unreasonable.[177] Whereas some device platforms allow for goal modification, goals are typically defined at device set-up and many users are unaware of the capability of altering them. Further, apps and device companies are not explicit that this is a possibility.[173] Additionally, some users may not be aware as to an appropriate goal for an optimal challenge. Thus, WFT developers may suggest the user wear the WFT for a short time to establish a baseline of PA, and then prompt the user to choose a goal within a defined range.

Conclusions

The studies in this dissertation demonstrate that WFTs can positively impact PA in people with controlled motivation for PA, although it is likely that the behavior is only maintained in the short-term. When combined with MI, WFTs are also effective in improving autonomous motivation for PA, but not necessarily PA behavior. Finally, people with

autonomous motivation for PA may persist in using a WFT but it may only serve as a tool for collecting data, rather than a motivational cue.

Clearly, more research is required to better understand WFTs, motivation, and PA. The hypothetical model presented here may serve as a basis for future studies. In the meantime, WFT developers can improve their devices by personalizing feedback, rewards, and goals to better fulfill the psychological needs of autonomy, competence, and relatedness. Fulfillment of these needs predicts autonomous motivation that, in turn, predicts long-term PA, a necessary component for health, well-being, and longevity.

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APPENDIX A

Mixed-Methods Survey Questions

Colorado State University

Laboratory for Assessment and Promotion Physical Activity and Health

Physical Activity, Motivation, and Wearable Fitness Tracker Use Questionnaire

The information collected from these questions is very important for both our study and the future services applied to your community. Please answer ALL of those questions that apply to you.

Your answers will be kept confidential.

Motivation Questions

Please rate how much you agree or disagree with the following statements about your motivation for exercise. (**These items are from the BREQ-3- domains listed in bold will NOT be included in the participant version)**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. It's important to me to exercise regularly.	1	2	3	4	5
2. I don't see why I should have to exercise.	1	2	3	4	5
3. I exercise because it's fun.	1	2	3	4	5
4. I feel guilty when I don't exercise.	1	2	3	4	5
5. I exercise because it is consistent with my life goals.	1	2	3	4	5
6. I exercise because other people say I should.	1	2	3	4	5
7. I value the benefits of exercise.	1	2	3	4	5
8. I can't see why I should be exercising.	1	2	3	4	5
9. I enjoy my exercise sessions.	1	2	3	4	5
10. I feel ashamed when I miss an exercise session.	1	2	3	4	5
11. I consider exercise part of my identity.	1	2	3	4	5

12.	I take part in exercise because my friends/family/partner say I should.	1	2	3	4	5
13.	I think it's important to make an effort to exercise regularly.	1	2	3	4	5
14.	I don't see the point in exercising.	1	2	3	4	5
15.	I feel exercise is a pleasurable activity.	1	2	3	4	5
16.	I feel like a failure when I have not exercised in a while.	1	2	3	4	5
17.	I consider exercise a fundamental part of who I am.	1	2	3	4	5
18.	I exercise because others will not be pleased with me if I don't.	1	2	3	4	5
19.	I get restless if I don't exercise regularly.	1	2	3	4	5
20.	I think exercising is a waste of time.	1	2	3	4	5
21.	I get pleasure and satisfaction from participating in exercise.	1	2	3	4	5
22.	I would feel bad about myself if I was not making time to exercise.	1	2	3	4	5
23.	I consider exercise to be consistent with my values.	1	2	3	4	5
24.	I feel under pressure from my family/friends to exercise.	1	2	3	4	5

Physical Activity Questions

Think about the time you spend doing different types of physical activity in a typical week. Please answer these questions even if you do not consider yourself to be a physically active person.

Work

Think first about the time you spend doing work. Think of work as things that you have to do such as paid or unpaid work, studying/training, household chores, harvesting food/crops, fishing/hunting for food, seeking employment, etc. In answering the following questions, "vigorous-intensity activities" are activities that require hard physical effort and cause large increases in breathing or heart rate, "moderate-intensity activities" are activities that require moderate physical effort and cause small increases in breathing or heart rate.

25. Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate like carrying or lifting heavy loads, digging, or construction work for at least 10 minutes continuously?

Yes

No

If "No," ***skip to question 28***

26. In a typical week, on how many days so you do vigorous-intensity activities as part of your work?

_____ days per week

27. How much time do you spend doing vigorous-intensity activities at work on a typical day?

_____ hours per day _____ minutes per day

28. Does your work involve moderate-intensity activity, that causes small increases in breathing or heart rate such as brisk walking or carrying light loads for at least 10 minutes continuously?

Yes

No

If "**No,**" ***skip to question 31***

29. In a typical week, on how may days do you do moderate-intensity activities as part of you work?

_____ days per week

30. How much time do you spend doing moderate-intensity activities at work on a typical day?

_____ hours per day _____ minutes per day

Travel To and From Places

The next questions exclude the physical activities at work you have thought of above. Now, think about the usual way you travel to and from places. For example, going to work, to shopping, to your place of worship, etc.

31. Do you walk or use a bicycle for at least 10 minutes continuously to get to and from places?

Yes

No

If "**No,**" ***skip to question 34***

32. In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?

_____ days per week

33. How much time do you spend walking or bicycling for travel on a typical day?

_____ hours per day _____ minutes per day

Recreational Activities

The next questions exclude the work and transport activities that you have thought of above. Think about sports, fitness, and recreational activities that you engage in.

34. Do you do any vigorous-intensity sports, fitness, or recreational activities that cause large increases in breathing or heart rate like running or rowing for at least 10 minutes continuously?

Yes

No

If "**No,**" ***skip to question 37***

35. In a typical week, on how many days do you do vigorous intensity sports, fitness, or recreational activities?

_____ days per week

36. How much time do you spend doing vigorous-intensity sports, fitness, or recreational activities on a typical day?

_____ hours per day _____ minutes per day

37. Do you do any moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate such as brisk walking, cycling, or dancing for at least 10 minutes continuously?

Yes

No

If **"No,"** ***skip to question 40***

38. In a typical week, on how many days do you do moderate-intensity sports, fitness, or recreational activities?

_____ days per week

39. How much time do you spend doing moderate-intensity sports, fitness, or recreational activities on a typical day?

_____ hours per day _____ minutes per day

Sedentary Behaviors

The following question is about time you spend sitting or reclining at work, at home, getting to and from places, or with friends including time spent sitting at a desk, sitting with friends, traveling in car, bus, train, reading, playing cards or watching television, but do not include time spent sleeping.

40. How much time do you usually spend sitting or reclining on a typical day?

_____ hours per day _____ minutes per day

Wearable Fitness Tracker Use Questions

Please answer the following questions about your wearable fitness tracker use.

41. Are you currently using a wearable fitness tracker?
A. Yes, I'm currently using a wearable fitness tracker.
B. No, I previously used a wearable.

42. What wearable fitness tracker do you/did you use? (Choose all the apply)

A. Apple Watch
B. Fitbit (Charge HR, Alta, Flex, Versa, Zip)
C. Whoop Band
D. Under Armour UA Band
E. Samsung Gear
F. Garmin Vivosport
G. Other (please indicate) _____
H. Do not know/Prefer not to answer

43. Branching logic question:

a. How long did you use the _____?
    i. Less than one month
    ii. One to three months
    iii. More than three months
b. How did you get the_____?
    i. I bought it for myself
    ii. It was a gift
    iii. It was provided to me by my workplace
    iv. It was provided to me by my health insurance
    v. Other (please indicate) _____
    vi. Do not know/Prefer not to answer
c. Why did you stop using the_____?
    i. It broke
    ii. It got lost
    iii. I did not like it
    iv. It did not help me meet my goals
    v. It was too hard to understand
    vi. It got boring
    vii. I learned everything I could from it
    viii. It was intrusive
    ix. Other (please specify) _____
    x. Do not know/Prefer not to answer

d. Please put the trackers in order from the first one you used to the latest one you used. For example, if you used an Apple Watch in 2010 and a Fitbit in 2012, Apple Watch will be first, Fitbit will be second.

44. Do/did your wearable fitness tracker have a daily physical activity goal?

A. Yes

B. No

45. Please specify your daily physical activity goal as defined by your wearable fitness tracker:

A. Active minutes

B. Step number

C. Hours of sleep

D. Calories burned

E. Calories consumed

F. Other (please specify) _____

G. Do not know/Prefer not to answer

46. Before you got your wearable fitness tracker, how many days per week, on average, did you get 30 minutes of moderate to vigorous physical activity?

A. 0 days per week
B. 1-2 days per week
C. 3-4 days per week
D. 5-7 days per week
E. Do not know/Prefer not to answer

FORMER WEARABLE FITNESS TRACKER USERS ONLY

Questions 47-80 are for individuals who formerly used a wearable fitness tracker but do not anymore. If you currently use a wearable fitness tracker, skip to question 81.

Think about the wearable fitness tracker that you used for the longest amount of time. Respond to the following questions with that tracker in mind.

47. How many days per week did you use your wearable fitness tracker?

A. 6-7 days per week

B. 3-5 days per week

C. 1-2 days per week

D. Less than 1 full day per week

E. Do not know/Prefer not to answer

Please rate your level of agreement with each of these statements:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
48. Using a wearable fitness tracker is important to improve my fitness.	1	2	3	4	5
49. Using a wearable fitness tracker is important to improve my health.	1	2	3	4	5
50. Using a wearable fitness tracker is important to improve my appearance.	1	2	3	4	5
51. Using a wearable fitness tracker is important to monitor my activity.	1	2	3	4	5
52. I used my wearable fitness tracker to compete with friends and family on the associated mobile application or website.	1	2	3	4	5
53. I had a wearable fitness tracker because I like to keep up with the latest technology.	1	2	3	4	5
54. I used a wearable fitness tracker because my friends and/or family members used one.	1	2	3	4	5

55. How happened to your physical activity after you started using your wearable fitness tracker, compared to before you started using it?

A. It did not change

B. It increased a lot

C. It increased a little

D. It decreased a lot

E. It decreased a little

F. Do not know/Prefer not to answer

56. How happened to your physical activity after you STOPPED using your wearable fitness tracker, compared to when you used it?

A. It did not change

B. It increased a lot

C. It increased a little

D. It decreased a lot

E. It decreased a little

F. Do not know/Prefer not to answer

Please rate your level of agreement with the following statements:

When I used to use my wearable fitness tracker:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
57. It was important to me to meet my wearable fitness tracker goal regularly.	1	2	3	4	5
58. I didn't see why I should have to meet my wearable fitness tracker goal.	1	2	3	4	5
59. I met my wearable fitness tracker goal because it was fun.	1	2	3	4	5
60. I feel guilty when I didn't meet my wearable fitness tracker goal.	1	2	3	4	5
61. I met my wearable fitness tracker goal because it is consistent with my life goals.	1	2	3	4	5
62. I met my wearable fitness tracker goal because other people said I should.	1	2	3	4	5
63. I valued the benefits of meeting my wearable fitness tracker goal.	1	2	3	4	5
64. I couldn't see why I should meet my wearable fitness tracker goal.	1	2	3	4	5
65. I enjoyed meeting my wearable fitness tracker goal.	1	2	3	4	5
66. I felt ashamed when I didn't meet my wearable fitness tracker goal.	1	2	3	4	5
67. I considered meeting my wearable fitness tracker goal to be part of my identity.	1	2	3	4	5
68. I met my wearable fitness tracker goal because my friends/family/partner said I should.	1	2	3	4	5
69. I thought it was important to make an effort to meet my wearable fitness tracker goal.	1	2	3	4	5
70. I didn't see the point in meeting my wearable fitness tracker goal.	1	2	3	4	5

71.	I felt that meeting my wearable fitness tracker goal was a pleasurable activity.	1	2	3	4	5
72.	I felt like a failure when I had not met my wearable fitness tracker goal in a while.	1	2	3	4	5
73.	I considered meeting my wearable fitness tracker goal a fundamental part of who I am.	1	2	3	4	5
74.	I met my wearable fitness tracker goal because others would not be pleased with me if I don't.	1	2	3	4	5
75.	I got restless if I didn't meet my wearable fitness tracker goal regularly.	1	2	3	4	5
76.	I thought meeting my wearable fitness tracker goal was a waste of time.	1	2	3	4	5
77.	I got pleasure and satisfaction from meeting my wearable fitness tracker goal.	1	2	3	4	5
78.	I would feel bad about myself if I was not meeting my wearable fitness tracker goal.	1	2	3	4	5
79.	I considered meeting my wearable fitness tracker goal to be consistent with my values.	1	2	3	4	5
80.	I felt pressure from my family/friends to meet my wearable fitness tracker goal.	1	2	3	4	5

CURRENT WEARABLE FITNESS TRACKERS ONLY

Questions 81-112 are for individuals who currently use a wearable fitness tracker. If you do not currently use a wearable fitness tracker, please skip to question 113.

Think about the wearable fitness tracker that you currently use. Respond to the following questions with that tracker in mind.

81. How many days per week do you use your wearable fitness tracker?

A. 6-7 days per week

B. 3-5 days per week

C. 1-2 days per week

D. Less than 1 full day per week

Please rate your level of agreement with each of these statements:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
82. Using a wearable fitness tracker is important to improve my fitness.	1	2	3	4	5
83. Using a wearable fitness tracker is important to improve my health.	1	2	3	4	5
84. Using a wearable fitness tracker is important to improve my appearance.	1	2	3	4	5
85. Using a wearable fitness tracker is important to monitor my activity.	1	2	3	4	5
86. I use my wearable fitness tracker to compete with friends and family on the associated mobile application or website.	1	2	3	4	5
87. I have a wearable fitness tracker because I like to keep up with the latest technology.	1	2	3	4	5
88. I use a wearable fitness tracker because my friends and/or family members use one.	1	2	3	4	5

Please rate your level of agreement with the following statements:

Since I started using my wearable fitness tracker:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
89. It is important to me to meet my wearable fitness tracker goal regularly.	1	2	3	4	5
90. I don't see why I should have to meet my wearable fitness tracker goal.	1	2	3	4	5
91. I meet my wearable fitness tracker goal because it is fun.	1	2	3	4	5

92.	I feel guilty when I don't meet my wearable fitness tracker goal.	1	2	3	4	5
93.	I meet my wearable fitness tracker goal because it is consistent with my life goals.	1	2	3	4	5
94.	I meet my wearable fitness tracker goal because other people say I should.	1	2	3	4	5
95.	I value the benefits of meeting my wearable fitness tracker goal.	1	2	3	4	5
96.	I can't see why I should meet my wearable fitness tracker goal.	1	2	3	4	5
97.	I enjoy meeting my wearable fitness tracker goal.	1	2	3	4	5
98.	I feel ashamed when I don't meet my wearable fitness tracker goal.	1	2	3	4	5
99.	I consider meeting my wearable fitness tracker goal to be part of my identity.	1	2	3	4	5
100.	I meet my wearable fitness tracker goal because my friends/family/partner say I should.	1	2	3	4	5
101.	I think it is important to make an effort to meet my wearable fitness tracker goal.	1	2	3	4	5
102.	I don't see the point in meeting my wearable fitness tracker goal.	1	2	3	4	5
103.	I feel that meeting my wearable fitness tracker goal is a pleasurable activity.	1	2	3	4	5
104.	I feel like a failure when I have not met my wearable fitness tracker goal in a while.	1	2	3	4	5
105.	I consider meeting my wearable fitness tracker goal a fundamental part of who I am.	1	2	3	4	5
106.	I meet my wearable fitness tracker goal because others would not be pleased with me if I don't.	1	2	3	4	5
107.	I get restless if I don't meet my wearable fitness tracker goal regularly.	1	2	3	4	5

108.	I think meeting my wearable fitness tracker goal is a waste of time.	1	2	3	4	5
109.	I get pleasure and satisfaction from meeting my wearable fitness tracker goal.	1	2	3	4	5
110.	I feel bad about myself if I am not meeting my wearable fitness tracker goal.	1	2	3	4	5
111.	I consider meeting my wearable fitness tracker goal to be consistent with my values.	1	2	3	4	5
112.	I feel pressure from my family/friends to meet my wearable fitness tracker goal.	1	2	3	4	5

ALL RESPONDANTS

Sociodemographic Questions - please answer the following questions to the best of your ability.

113. **Sex** (Biological sex assigned at birth)
a. Male
b. Female
c. Do not know/prefer not to answer

114. What is your **gender** identity?
a. Male

b. Female

c. Other (please indicate):_____

d. Do not know/prefer not to answer

115. Please enter your **date of birth** ____MM___DD_____Year_

116. Please enter your **age** _____Years

117. Please enter your **body weight** in pounds:_____

118. Please enter your **height**: _____ feet _____inches

119. If you are female, are you pregnant?

a. Yes
b. No
c. Don't know/prefer not to answer

120. Please indicate which, if any, of the following chronic health problems you have. (Check all that apply)
a. High blood pressure
b. Cataracts or other eye problems
c. Heart disease/heart attack
d. Arthritis or Rheumatism
e. Stroke
f. Cancer
g. Broken or fractured bones
h. Bronchitis or other respiratory diseases
i. Diabetes
j. Chronic foot trouble (bunions, plantar fasciitis, ingrown toenails, etc.)
k. None
l. Other, please specify:_____

121. I think my physical health is:
a. Poor
b. Fair
c. Good
d. Very Good
e. Excellent
f. Don't know/Prefer not to answer

Race

122. Please specify your race (Check all that apply)
a. White or Caucasian
b. Black or African American
c. Native American or American Indian
d. Asian
e. Native Hawaiian or Pacific Islander
f. Other
g. Do not know/prefer not to answer

Ethnicity

123. Please specify your ethnicity (Check one)
a. Hispanic or Latino
b. Non-Hispanic or Latino
c. Other
d. Do not know/prefer not to answer

Education

124. What is the highest level of education you have completed? (Check one)
   a. 12th grade or less
   b. High school graduate or GED
   c. Some college/AA degree/Technical school training
   d. College graduate (BA or BS degree)
   e. Graduate school degree: Master's or Doctorate degree (MD, PhD, JD)
   f. Do not know/prefer not to answer

School Status

125. If you are currently in school, please indicate the level you are enrolled?
   a. I am NOT in school
   b. High school
   c. Community college or technical school
   d. 4-year college/university
   e. Graduate or other professional school

Work Status

126. What is your current work situation?
   a. Working full time (≥ 40 hours/week)
   b. Working part time (20 - 40 hours/week)
   c. Working part time (<20 hours/week)
   d. Not working and not looking for work
   e. Unemployed and looking for work
   f. Disabled or retired and not looking for work
   g. Do not know/prefer not to answer

Income

127. What is your total combined family income for the past twelve months, before taxes, from all sources, wages, public assistance/benefits, help from relatives, alimony, and so on?

If you do not know your exact income, please estimate.

   h. Less than $12,500
   i. $12,500-$26,999
   j. $27,000-$43,999
   k. $44,000-$59,999
   l. $60,000-$74,999
   m. $75,000-$99,999
   n. $100,000-$149,000
   o. More than $150,000
   p. Don't know/ Prefer not to answer

Please enter your zip code _____

Semi-Structured Interview Questions

1. Do you currently use a wearable fitness tracker?
2. What type of tracker do you currently use?
3. What type of tracker did you use in the past?
4. Have long have you/did you use your wearable fitness tracker?
5. How did you get your most recently used tracker?
6. What are/were some of the functions of your wearable tracker that you use/used the most?
7. Does/did your wearable fitness tracker have a daily goal like steps, calories, active minutes, etc? If so, what is/was that goal?
8. How important is/was it for you to meet that daily goal?
9. Do you friends or family members own wearable fitness trackers? If so, how did their tracker use influence your decision to use a tracker yourself?
10. Some wearable fitness trackers allow you to compete with other people on a mobile application, for example. Tell me about your experience with this.
11. What are the benefits of using a wearable fitness tracker?
12. What are the drawbacks of using a wearable fitness tracker?
13. How does/did using a wearable fitness tracker influence your motivation for exercise?
14. What are the reasons that you continue/not continue to use a wearable fitness tracker?
15. Is there anything else you would like to say about wearable fitness trackers?