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Mini-Reviews

Wearables for Promoting Physical Activity

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BACKGROUND: The rapid expansion and popularity of consumer-wearable physical activity monitors (WPAMs) has enabled the integration of technology into physical activity (PA) intervention, deployment, and evaluation. This brief review reports on the accuracy of consumer-WPAMs, considers the intervention effects of using consumer-WPAMs, and offers future considerations as the proliferation of this area of product development and consumer use continues to escalate.

CONTENT: The studies reviewed document the utility for consumer-WPAMs to objectively assess PA, with output metrics similar to research-grade activity monitors. Early intervention efficacy for the use of consumer-WPAMs to increase PA holds considerable promise. Substantial increases in moderate- to vigorous-intensity PA (MVPA) have been reported across different research study designs and populations in which consumer-WPAMs have been used in isolation or in conjunction with other behavioral change strategies. The utility of consumer-WPAMs is currently being investigated in clinical populations, notably showing increases in PA in individuals at risk for cancer or post cancer survivors, in those with chronic obstructive pulmonary disease, and in postsurgical patients. There has been a proliferation of registered trials at clinicaltrials.gov, and an increase of disseminated works regarding the use of consumer-WPAMs is expected.

SUMMARY: There are many research studies documenting the validity and intervention effectiveness of consumer-WPAMs; evidence is emerging on the health benefits linked to use of such devices. Future work on the long-term effects of consumer-WPAMs on behavior and health is warranted, and prospects appear exciting as wearable technology advances and adoption increases.

Physical activity (PA)[3] and its health benefits are well-known and well-reported within the scientific literature. Routine PA is effective in the prevention and management of chronic diseases, such as, but not limited to, cardiovascular disease (CVD), hypertension, type 2 diabetes, and weight control/maintenance *(1)*. Despite these benefits, inactivity has become a global epidemic. Fortunately, inactivity is a modifiable risk factor with appropriate interventions. Well-designed PA interventions that incorporate behavior change components and instructions on how to engage in activity are imperative for health promotion and adoption.

Wearable physical activity monitors (WPAMs) provide opportunities to advance the assessment and promotion of PA, and there has been a proliferation of these devices within the past 8 years, with >400 wearable monitors currently in the market today, sold by over 250 different companies *(2)*. Between April 2013 and March 2014, 3.3 million WPAMs were sold *(3)*, and in 2015, Fitbit, 6 years after its initial launch as a WPAM, comprised 67% of the wearable fitness market *(3)*. In 2016, it was projected that the wearable industry would make $14 billion on "wrist-based" devices alone *(4)*, and consequently, the wearables market experienced a 3.1% increase in the third quarter of 2016 *(5)*. These numbers are expected to climb. It is projected that 411 million wearable devices will be sold in 2020, producing a $34 billion industry *(4)* that will continue to grow to a $51.6 billion industry by 2022 *(6)*. This growth is already evident, as basic wearables (i.e., fitness bands) accounted for 85% of the wearable market in 2016 *(5)*. The market continues to be driven by consumer demand and preferences for "sophisticated gadgets" and "next-generation" displays *(6)*. Although there are more options now than ever to track PA and other biometrics, the research and clinical communities are playing catch-up, trying to determine wearable device efficacy and to fully utilize this technological innovation. This Mini-Review will briefly examine different types of WPAMs, their validity, and their effectiveness as tools for increasing PA and promoting health. Recommendations are offered for future research to move this area of scientific inquiry forward.

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[3] Nonstandard abbreviations: PA, physical activity; CVD, cardiovascular disease; MET, metabolic equivalent; MVPA, moderate- to vigorous-intensity PA; COPD, chronic obstructive pulmonary disease; SPPB, short-performance physical battery.

Methods

A systematic review was conducted in accordance with the guidelines presented by the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA). We searched 5 electronic databases (Pubmed, SportDiscus, CINAHL, ProQuest, and Web of Science). Search terms used included individual terms or combinations of the following terms: Fitbit, Jawbone, Garmin, Withings/Nokia, Misfit, Sensewear, PA, exercise, tracker, monitor, step count, pedometer, accelerometer, wearable, consumer, self-monitoring, mobile health, mHealth, electronic device, validity, validation, and intervention. We also manually searched bibliographies of articles retrieved and personal article collections. We did not include abstracts, dissertations, case studies, or prior systematic reviews. In an effort to supplement prior reviews, we only included articles that were published or accepted for publication in peer-reviewed journals or conference proceedings after January 2015. For the purpose of examining the validity of device PA outcome measurement, prior reviews were included where relevant.

For the purpose of this Mini-Review, we will use the phrase consumer-WPAM to describe a consumer-grade WPAM that has the following characteristics: it is worn on the body; uses accelerometers, altimeters, or other sensor technology to assess body movement and/or physiological data; provides user feedback beyond step counts only; and uses a visual display for self-monitoring or is able to transfer data to another platform simultaneously or nearly simultaneously, i.e., to a smart phone, tablet or Internet site. Studies included for review had to satisfy the following: (*a*) include the use of the above-defined consumer-grade WPAM; (*b*) include adult populations of ≥18 years; (*c*) have a measure of either PA or health as an outcome; (*d*) have published after January 1, 2015 (excluding PA measurement validity articles); and (*e*) should be published in English. Studies were excluded if they only reported study protocols with no results. Resulting searches were screened in the following manner: (*i*) duplicates were removed, (*ii*) titles and abstracts were screened relative to inclusion and exclusion criteria, and (*iii*) full-text articles were further screened for inclusion and exclusion criteria. Using a standardized matrix, the following data were gleaned for all remaining studies: participant characteristics, study design, study description, name of the consumer-WPAM, and study outcomes.

Results

RESULTS OF SYSTEMATIC LITERATURE SEARCH

After removing article duplicates, in total, 834 publications were identified through database searching. Following screening of title and abstracts, 54 publications were reviewed in full; of these, the majority, 43, were validation or validation-comparison designs of consumer-WPAMs, with the remaining 11 falling under study designs using their use or effectiveness to modify PA or a health outcome. At this point, we refined our approach to include only a brief discussion on the validity of consumer-WPAMs by use of prior reviews where possible for brevity, and then reviewed the remaining studies extracted under the heading of intervention effectiveness of consumer-WPAMs, specifically examining (*a*) PA behavioral change using consumer-WPAMs *(17–23)*, (*b*) PA and health outcomes using consumer-WPAMs *(18, 23–26)*, and (*c*) use of consumer-WPAMs in clinical populations to promote PA and health *(27–31)*.

Table 1 reports on the studies included for review on the interventional effectiveness of consumer-WPAMs. Table 2 provides a description of the characteristics of many of the popular consumer-WPAM devices at the time of this review.

Discussion

As defined by Caspersen and colleagues in 1985 *(7)*, PA is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure." In this context, PA can either be structured or incidental. Structured activity, often called *exercise*, is something that is planned and purposeful for promoting health and fitness. Incidental activity is often utilitarian and a result of typical activities of daily living, including activity within different domains, namely, occupational activity, domestic activity, transportation/utilitarian activity, or leisure activity. In addition to PA stemming from different domains, it is also made up of different dimensions. The dimensions of PA include the mode or type, frequency, duration, and intensity of performing the activity. Table 3 provides an overview of PA domains and dimensions and provides contextual examples of each.

Historically, incidental PA has been difficult to measure and assess, in part due to its sporadic nature and place. As such there has been an emergence of objective PA monitoring devices used to both assess PA and establish relationships between PA and health. Objective PA monitoring devices that have become popular in the research realm and for use in activity interventions include pedometers (that measure steps), accelerometers (that measure the body or limb acceleration), and some combination devices that measure both acceleration and other physiological parameters such as heart rate, sweat rate, and skin temperature (i.e., BodyMedia, and ActiHeart devices). Terminology is important to clarify when it comes to the use of the words "wearable physical activity monitors" as other phrases exist, such as "exercise tracker," "activity tracker," "fitness tracker," "step tracker," "consumer activity tracker," and "activ-

Table 1 Physical activity and health promotion studies utilizing wearable monitors.

Author	Population	Device	Intervention	Main Outcomes	Results
Adams MA et al. *(21)*	N = 96 (77% women). Mean age 41 ± 9.5 years.	Fitbit Zip	2 × 2 factorial 12-week randomized trial. Gp1: Adaptive percentile, Gp 2: Static 10,000 steps, Gp 3: Immediate, Gp 4: Delayed rewards.	Increase in steps per day. Increase in MVPA.	Steps: On average all Gps[1] ↑ 2389 steps/d. Gp 1 ↑ 2149 steps/d; Gp 2 ↑ 2630 steps/d, Gp 3 ↑ 2762 steps/d, and Gp 4 ↑ 2016 steps/d.
	Mean BMI 34.1 ± 6.2		One-time educational materials, text prompts.		MVPA: On average all Gps ↑ 12.7 min/d. Gp 1 ↑ 11.5 min/d; Gp 2 ↑ 14.0 min/d, Gp 3 ↑ 15.0 min/d, and Gp 4 ↑ 10.4 min/d.
Cadmus-Bertram LA et al. *(20)*	N = 51 women. Mean age 59.9 ± 7.0 years.	Fitbit One	16-week RCT. Gp 1: Fitbit One + Website, plus telephone call at 4-week. Gp 2: Basic pedometer and printed materials.	MVPA total and bouts in min/week, steps per day, by Actigraph.	MVPA Total min/week: Gp 1: Baseline to post ↑ 62 min/week. Gp 2: Baseline to post ↑ 13 min/week.
	Mean BMI 29.10.9 ± 3.6				MVPA Bout min/week: Gp 1: Baseline to post ↑ 38 min/week. Gp 2: Baseline to post ↑ 16 min/week.
					Steps/d: Gp 1: Baseline to post ↑ 789 steps/d. Gp 2: Baseline to post ↑ 362 steps/d.
Rowley TW et al. *(23)*	N = 170 (80% women). Mean age 67.3 ± 6.2 years.	Omron HJ-720ITC	12-week RCT. Gp1: Control, Gp2: pedometer 10,000 step goal, Gp 3: tailored-internet and pedometer feedback	Increase in steps per day.	Steps: Gp 1 ↓ 36 steps/d; Gp 2 ↑ 2016 steps/d, Gp 3 ↑ 5598 steps/d.
	Mean BMI 29.6 ± 3.8				
Finkelstein EA et al. *(22)*	N = 800 employees from 13 organizations aged 21–65 years.	Fitbit Zip	6-month RCT with 6-month follow up. Gp 1: Control, Gp 2: Fitbit, Gp 3: Fitbit + Charity incentives, Gp 4: Fitbit + Cash incentives. Incentives tied to meeting weekly step goals.	MVPA bouts in min/week by Actigraph.	MVPA Bout min/week at 6 months: Compared to Gp 1 control, Gp 2 ↑ 16 min/week, Gp 3 ↑ 21 min/week, and Gp 4 ↑ 29 min/week.
					MVPA Bout min/week at 12 months: Compared to Gp 1 control baseline, Gp 2 ↑ 37 min/week, Gp 3 ↑ 32 min/week, and Gp 4 ↑ 15 min/week.

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Table 1 Physical activity and health promotion studies utilizing wearable monitors. *(Continued from page 55)*

Author	Population	Device	Intervention	Main Outcomes	Results
Gell NM et al. *(29)*	N = 24 cancer survivors	Fitbit One	Post 12-week oncology exercise rehabilitation, 4-week intervention to maintain PA levels post discharge. Participants provided Fitbit One, and text messages, BCS and goal setting from a single meeting at discharge, plus map of community resources. Biweekly 15 min phone call.	MVPA and Steps/d by Actigraph	MVPA: Discharge to 4 week = ↓ 12.8 min
					Steps: Discharge to 4 week = ↓ 668 steps/d.
Hartman SJ et al. *(28)*	N = 54 women at increased risk for breast cancer. Mean age 59.5 ± 5.6 years.	Fitbit One	6-month weight loss RCT. Gp 1: Weight loss dietary goals + Fitbit + 12 30 min phone calls. Gp 2: Control.	Weight change and MVPA by Actigraph.	Weight loss: Gp 1: ↓ 4.4 ± 4.3 kg (5.3%), Gp 2: ↓ 0.8 ± 3.8 kg (1%).
	Mean BMI 31.9 ± 3.5				MVPA: Gp 1: ↑ 15.0 ± 14.2 min/d, Gp 2: ↑ 10.9 ± 10.1 min/d.
Jakicic JM et al. *(25)*	N = 471 (71% women). Median age 30.9 years.	BodyMedia	24-month weight loss RCT. Gp 1: Standard behavioral intervention. Gp 2: Technology enhanced intervention.	Weight change. MVPA bouts in min/week by the Sensewear Pro armband.	Weight loss: Month 6 Gp 1: ↓ 8.6 kg, Gp 2: ↓ 8.0 kg. Month 24 Gp 1: ↓ 5.9 kg, Gp 2: ↓ 3.5 kg compared to baseline.
	Median BMI 31.2.				MVPA Bout min/week: Month 6 Gp 1: ↑ 189.1 min/week, Gp 2: ↑ 113.1 min/week. Month 24 Gp 1: ↑ 134.3 min/week, Gp 2: ↑ 107.6 min/week compared to baseline.
Lyons EJ et al. *(24)*	N = 40 (85% women). Mean age 61.5 ± 5.6 years.	Jawbone Up24	12-week RCT, Intervention vs waitlist control. Intervention received Jawbone, tablet with app installed, weekly telephone counseling. Weekly goals.	Physical activity and sedentary time by ActiPAL. Body composition by DEXA.	Stepping time/d: Intervention ↑ 51.4 min/d.

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Table 1 Physical activity and health promotion studies utilizing wearable monitors. *(Continued from page 56)*

Author	Population	Device	Intervention	Main Outcomes	Results
	Mean BMI 30.3 ± 3.5				Steps: Intervention ↑ 1091 steps/d.
					Body fat: Intervention ↓ 0.25%.
					Body weight: Intervention ↓ 0.86 kg.
McMahon SK et al. *(26)*	N = 102 (75% women). Mean age 79 ± 6 years.	Fitbit One	2 × 2 Factorial 8-week RCT with 6-month follow up.	Physical activity duration.	Physical activity duration: Gp 1 post = ↓ 12 min/d, 6-month post = ↓ 19 min/d compared to baseline. Gp 2 post = ↑ 250 min/d, 6-month post = ↑ 117 min/d compared to baseline. Gp 3 post = ↑ 77 min/d, 6-month post = ↑ 81 min/d compared to baseline. Gp 4 post = ↑ 192 min/d, 6-month post = ↑ 266 min/d compared to baseline.
			Gp1: PA program + Fitbit, Gp 2: PA program + Fitbit + interpersonal BCS, Gp 3: PA program + Fitbit + intrapersonal BCS, Gp 4: PA program + Fitbit + interpersonal + intrapersonal BCS.	Short Performance Physical Battery (SPPB).	SPPB: Gp 1 post = ↑ 0.3, 6-month post = ↑ 0.1 compared to baseline. Gp 2 post = ↑ 0.4, 6-month post = ↑ 0.5 compared to baseline. Gp 3 post = ↓ 0.2, 6-month post = ↓ 0.5 compared to baseline. Gp 4 post = ↑ 0.9, 6-month post = ↑ 1.0 compared to baseline.
Moy ML et al. *(27)*	N = 238 (94% male)	Omron HJ-720ITC	4-month intervention with 8-month follow up. Gp 1: Enhanced pedometer plus BCS website. Gp 2: Waitlist control.	Respiratory questionnaire. Daily step count.	SGRQ: 12-month difference from baseline, Gp 1: ↓ 2.5, Gp 2: ↓ 1.4.
	Mean age 66.8 ± 8.8 years.				Step/d: 12-month difference from baseline, Gp 1: ↑ 270 steps/d, Gp 2: ↑ 163 steps/d.
	Mean BMI 29.10.9 ± 3.6				
Wang JB et al. *(19)*	N = 67 (91% women). Mean age 48.2 ± 5.6 years.	Fitbit One	6-week RCT. Gp 1: Fitbit One + Text messaging. Gp 2: Fitbit One alone.	MVPA total min/week, steps per day, by the Actigraph.	MVPA Total min/week: Gp 1: Baseline to post ↓ 1.1 min/week. Gp 2: Baseline to post ↑ 4.3 min/week.
					Steps/d: Gp 1: Baseline to post ↑ 24 steps/d. Gp 2: Baseline to post ↓ 433 steps/d.

Gp, group; RCT, randomized clinical trial; BMI, body mass index; BCS, Behavioral Change Strategies; DEXA, dual-energy x-ray absorptiometry; SGRQ, St George's Respiratory Questionnaire.

Table 2 Wearable physical activity monitor device sample characteristics.

Brand	Model Name	Size, height × width	Weight, pounds	Cost (U.S. dollars)	Steps	Calories	Distance	Sleep	Heart Rate	Floors	Reminder to Move	Water Resistant
Fitbit https://www.fitbit.com/home	Zip	1.4 × 1.1 in	0.018	59.95	X	X	X	–	–	–	–	–
	One	2 × 0.75 in	0.02	99.95	X	X	X	X	–	X	–	–
	Flex 2	0.45 (width) In	NR	59.95	X	X	X	X	–	–	X	X
	Alta Activity Tracker	0.41 × 0.59 in	0.07	129.95	X	X	X	X	–	–	X	X
	Alta HR Activity Tracker + HR	1.6 × 0.6 in	0.05	149.95	X	X	X	X	X	–	X	X
	Charge 2	0.5 × 0.9 in	0.08	149.95	X	X	X	X	X	X	X	X
	Blaze	1 × 1.66 in	1.55	199.95	X	X	X	X	X	X	X	X
	Surge	0.38 × 1.38 in	0.169	249.95	X	X	X	X	X	X	–	–
Jawbone https://jawbone.com/	UpMove	9.21 × 3.18 in	NR	38.99	X	X		X	–	–	–	–
	Up2	NR	0.4	19.99–36.99	X	X		X	–	–	X	–
	Up3	NR	NR	49.99–99.99	X	X		X	X	–	X	–
Nokia (formerly Withings) http://www.health.nokia.com	Go	36 mm	NR	49.95	–	X	X	X	–	–	X	X
	Steel	36 mm	NR	129.95	–	X	X	X	–	–	X	X
	Steel HR	36 or 40 mm	NR	179.95	–	X	X	X	X	–	X	X
Misfit https://misfit.com	Ray	0.5 × 0.5 in	0.02	79.99–99.99	X	X	X	X	–	–	X	X
	Shine 2	7.28 in × 1.57 in	0.37	79.99–99.99	X	X	X	X	–	–	X	X
	Flare	8 mm (height)	0.02	49.99	X	X	X	X	–	–	–	X
	Shine	27.5 mm × 27.5 mm	0.02	29.99	X	X	X	X	–	–	–	X
	Flash	28.5 mm × 28.5 mm	0.01	11.99	X	X	X	X	–	–	–	–
Garmin http://www.garmin.com	Vivo-smart 3	9.6 mm × 19.2 mm	0.04	139.99	X	X	X	X	X	X	X	X
	Vivo-active HR	20.7 mm × 28.6 mm	0.10	249.99	X	X	X	X	X	X	X	X
	Approach S60	1.2 in (diameter)	0.11	399.99	X	X	X	X	X	–	X	X
	Vivofit 3	10 mm × 10 mm	0.06	99.99	X	X	X	X	–	–	X	X
	Vivo-smart HR+	25.3 mm × 10.7 mm	0.07	179.99	X	X	X	X	X	X	X	X
	Vivo-smart HR	25.3 mm × 10.7 mm	0.07	129.99	X	X	X	X	X	X	X	X
	Vivo-move		0.11–0.14	149.99	X	–	–	X	–	–	X	–

Key: "X" = yes, – = no; NR: Not Reported; ACC: accelerometer, HR: heart rate.

Table 3 Dimensions and domains of physical activity behavior.

	Definition and context
Physical activity dimension	
Mode	Specific activity performed (e.g., walking, gardening, cycling, etc.). Also defined in context of physiological demands/types (e.g. aerobic vs anaerobic activity, strength training, or balance and stability training).
Frequency	Number of sessions per day or per week, often qualified as the number of sessions (bouts) of at least 10 min in duration/length.
Duration	Time (minutes or hours) of the activity bout during a specified time frame (e.g., day, week, year, past month, etc.).
Intensity	Rate of energy expenditure. Intensity is an indicator of the metabolic demand of an activity. It can be objectively quantified with physiological measures (e.g., oxygen consumption or heart rate) or quantified by body movement (e.g., stepping rate, or body accelerations).
Physical activity domain	
Occupational	Work-related: involving walking, carrying or lifting objects.
Domestic	Housework, yard work, child care, chores, self-care, or incidental activities.
Transportation/Utilitarian	Purpose of going somewhere: typically walking or bicycling.
Leisure-time	Discretionary or recreational activities: sports, exercise, other hobbies in leisure.

ity or exercise monitor." There is also a distinction between research-grade WPAMs and commercial or consumer-WPAMs. Research-grade monitors largely store all data collected, often in high resolution, for weeks or even months at a time, on the device itself or it can be uploaded to a cloud application, primarily for use by the research team. Common research-grade WPAMs used include the Actigraph, the Actical device, or the activPAL device. Consumer-WPAMs typically do not collect data in such high resolution, but they have the added ability to simultaneously or frequently transfer data from the device to another visible platform such as a website or a smartphone for viewing by the consumer.

ACCURACY OF WEARABLE PHYSICAL ACTIVITY MONITORS

Other published works *(8)* have reviewed the full extent of how research-grade WPAMs work, which extends to the technology of consumer-WPAM devices. In brief, integrated microelectromechanical or piezo-electric or resistance elements in the sensor detect changes in the wearer's acceleration or posture, and these data are used in on-board algorithms to provide metrics on PA (dimension—frequency, intensity, duration) or inactivity (sitting) behavior. Algorithms used to assess PA are continually improving, but a notable concern with consumer-WPAM algorithms is that these are typically propriety and unknown, and modifications to such algorithms are not always reported by the consumer manufacturer. This represents a significant concern for interventionist research using these devices over time or for trying to compare research results over time.

QUANTIFYING PHYSICAL ACTIVITY OUTCOMES FROM WEARABLE PHYSICAL ACTIVITY MONITORS

PA is a movement behavior that results in an increase in energy expenditure above resting levels. The rate of energy expenditure is directly linked to the intensity of the PA. Other review articles have provided in-depth explanations of inferences drawn from PA engagement *(9)*. In brief, WPAMs measure movement, and this movement unit is typically recorded as a *step* or an acceleration signal, for instance, a *count* or a *g per second* (*g* referring to the force of acceleration due to gravity at the Earth's surface). This movement unit is then converted by an internal WPAM algorithm to other common PA outcomes, such as energy expenditure in *kilocalories.* Kilocalories are directly linked to the amount of oxygen consumed per minute during an activity, with kilocalorie estimates derived from internal algorithms that estimate oxygen consumption and multiply that rate by intensity and duration to arrive at a total kilocalorie estimate per activity, per hour, or per day. Similarly, another common PA metric outcome is a *metabolic equivalent* or *MET*. This is a common term used to express PA intensity. One MET represents the resting energy expenditure during quiet sitting, and multiples of this are therefore indicative of increases in exercise intensity. Common delineations of $<$1.5 METs and 1.5–2.9 METs, 3.0–5.9 METs, and $\geq$6.0 METs are equal to sedentary behavior and light-, moderate-, and vigorous-intensity activity, respectively. For instance, some common consumer-WPAM device outcomes will reveal how many minutes per day the consumer spent in moderate- to vigorous-intensity PA (MVPA).

Consumer-WPAMs therefore have unit values of measurement (i.e., steps, counts, g forces) and conversion values of measurement (i.e., kilocalories, METs, time spent in PA intensity ranges), a distinction that is important when examining the validity of these monitors.

VALIDITY OF MEASUREMENT

Before utilizing consumer-WPAM devices in any activity intervention or promotion, it is imperative to establish the validity of the device, which, as described by Bassett and colleagues *(10)*, would entail both unit and conversion calibration and criterion-referenced validity compared with known assessment standards. Below, we briefly examine the validity of some evaluated consumer-WPAMs separated by different commonly reported PA intervention outcomes. To date, there is a lack of published works on other WPAM metrics often used in consumer devices, such as stairs climbed or total distance walked.

STEPS PER DAY

Evenson et al. *(11)* recently performed a systematic review of 22 different studies pertaining to the validity and reliability of numerous Fitbit and Jawbone consumer-WPAMs. Criterion-referenced validity was high (mean correlations >0.80) compared with that in research-grade monitors for both in-laboratory and free-living scenarios. The cited research noted increases in step-counting error rates at slow gait/walking speeds *(11)*, which may be of paramount relevance to older individuals. For instance, Simpson and colleagues *(12)* noted that in a sample of older adults aged 73 years, for walking trials of 0.3–0.9 m/s, a waist-worn consumer-WPAM recorded zero steps for the slowest walking trials. This level of error is therefore likely to extend to clinical populations who have slower walking gait speeds. For expanding the consumer-WPAM market for widespread adoption across different populations, this level of error warrants further investigation and refinement and would benefit from consumer-WPAM industry research partnerships to increase the precision and accuracy of PA outcomes.

ENERGY EXPENDITURE AND TIME SPENT IN INTENSITY CLASSIFICATIONS

When going from a movement unit to a conversion unit, such as movement to kilocalories or METs, there is another level of error that is introduced, and both consumer- and research-WPAMs have increased error rates for these conversion units. Criterion-referenced validity has often used indirect calorimetry as a gold standard for comparison to evaluate the validity of consumer-WPAMs during simulated tasks of daily living. Error ranges for energy expenditure have been reported in the 10%–32% range, with differences noted to be activity- and task-dependent *(13, 14, 15)*. Consumer-WPAMs tend not to be equivalent to one another or to research-grade WPAMs for estimations of energy expenditure or time spent in MVPA *(16)*, and thus they are generally not suitable as measurement tools for precise estimates of energy expenditure. Nevertheless, they are useful for interventions of behavior change by giving feedback to the user on trends in rates of energy expenditure over time.

INTERVENTION EFFECTIVENESS OF WEARABLE PHYSICAL ACTIVITY MONITORS

Consumer-WPAMs enable immediate or frequent feedback loops to the consumer or participant. This feedback is the basis for using these devices for behavioral interventions to not only track but also promote increases in PA and health. A recent review by Lyons and colleagues *(17)* found that of 13 different consumer-WPAMs evaluated, a little over three-quarters of the devices used up to the following 6 different behavioral change techniques: goal setting, review of goals, discrepancies between behavior and goals, feedback, self-monitoring, and environmental support. Consumer-WPAMs are also starting to enable sharing personal profiles with family and friends, thus promoting social support, competition, and cooperation. In the following sections, we briefly review the use of consumer-WPAMs to increase PA and improve health, and we evaluate current use in different clinical populations.

PROMOTING PHYSICAL ACTIVITY BEHAVIORAL CHANGE

A testament to the proliferation of consumer-WPAM use can be seen in the number of trials registered with clinicaltrials.gov, which as of June 2017, stands at 141 studies, with PA listed as a primary or secondary outcome. The growing number of published studies reporting results of PA promotion efforts have facilitated new literature reviews on this topic. Recently, Bian et al. conducted a metaanalysis on the effect of technology-mediated diabetes prevention interventions on body weight and reviewed studies published between 2003–2015, with many employing WPAMs partnered with other technological platforms, such as Internet or text *(18)*. The results from this metaanalysis showed efficacy, with a pooled weight loss effect of 3.76 kg for the studies reviewed. Specifically, in this Mini-Review, we will focus on recent publications since January 2015 that have used consumer-WPAMs as a main intervention stimulus to provide feedback to the participant to elicit behavior change in PA or health.

In 2015, both Wang et al. *(19)* and Cadmus-Bertram et al. *(20)* used the Fitbit One to conduct 6- and 16-week randomized controlled trials, primarily in women, with mean ages of 48.2 and 59.9 years, respectively. Both trials used a 2-group design and employed the Actigraph accelerometer as an objective PA outcome, reporting minutes of MVPA and the number of steps per day. Wang et al. *(19)* showed that the Fitbit One used alone successfully increased MVPA by 4.3 mins per week on average but with a modest decrease in steps per day. Cadmus-Bertram and colleagues *(20)* revealed that the Fitbit One used in conjunction with Internet feedback and a single phone counseling session increased MVPA by 62 min per week and increased steps per day on average by 782. Discrepancies across these 2 trial results might be explained by the difference in intervention duration, with 6 weeks not likely to be sufficient to evoke meaningful behavioral change.

In 2017, Adams et al. *(21)* examined the impact of adding immediate or delayed financial rewards to either a static 10 000 step-per-day goal or to an adaptive percentile increase in per-week-step goal in a 12-week randomized trial using the Fitbit Zip in approximately 100 individuals with a mean age of 41 years. Overall, all groups increased MVPA by 12.7 min per day and increased mean steps per day by 2389. Adaptive goals were more successful than static goals, with little difference between immediate or delayed financial reward. Finkelstein et al. *(22)* also used the Fitbit Zip in a large study of 800 employees across 13 different organizations aged 21–65 years. In a 6-month randomized controlled trial with 6-month follow-up design, either immediate cash or charity incentives were added to weekly goals determined and monitored by the Fitbit. At 6 months, compared to the control group, all intervention arms increased their MVPA, with the Fitbit plus cash incentive group increasing the most by an average of 29 min per day. At 6-month follow-up, the Fitbit used alone with no reward outperformed all other groups, with an average increase of 37 min of MVPA per day, showing that PA levels were not maintained in other groups after financial incentives were removed *(22)*. Also in 2017, Rowley et al. *(23)* used the downloadable Omron pedometer partnered with a behavioral change Internet site to examine increases in steps per day in inactive older adults compared with a control group and a group using only a basic pedometer with a 10 000-step goal during a 12-week intervention. Post intervention, the pedometer plus interactive group experienced the greatest increase in steps per day, increasing steps by 119%, compared with the pedometer-only group at 62% and no change in the control group *(23)*. To date, the majority of studies have employed intervention durations primarily limited to short-term 6–16 weeks; only the Finkelstein et al. *(22)* study examined longer-term effects with a 6-month post intervention follow-up. Some studies have begun to examine the use of consumer-WPAMs partnered with other intervention structures, such as incentives, but to date, limited evidence exists on singular device-specific behavioral features that promote changes in PA.

PROMOTING PHYSICAL ACTIVITY AND HEALTH OUTCOMES

In addition to recent reviews on the impact of consumer-WPAMs on weight loss *(18)*, new studies have been published on this topic. Specifically, Lyons et al. *(24)* recently investigated the use of the Jawbone Up24 in 40 obese women and men aged 61.5 years. In this 12-week randomized control trial, the impact of receiving the Jawbone, plus a tablet with the application installed, including weekly goals and telephone counseling, revealed that the stepping time per day increased by approximately 51 min per day (assessed by activPAL). In this same trial, body weight decreased by approximately 1 kg and body fat percentage decreased by 0.25%. In a much larger trial of 471 men and women aged 30.9 years, Jakicic et al. *(25)* evaluated the benefit of adding technology by way of a BodyMedia armband to a weight loss intervention after 6 months, and evaluated 24-month outcomes. Both groups decreased weight at 24 months, 5.9 and 3.5 kg for the standard vs the technology group, respectively. The authors concluded that devices that monitor and provide feedback on PA levels may not add any advantage to weight loss over standard behavioral weight loss approaches.

In an 8-week randomized trial with 6-month follow-up, McMahon et al. *(26)* recently evaluated the use of the Fitbit One and different behavioral change strategies in a group of 102 older adults, mean age 79.6 years. In the group that employed the Fitbit in conjunction with a PA program and inter- and intrapersonal behavioral change strategies, PA duration increased by 266 min per day by month 6. Of further interest, scores from the short-performance physical battery (SPPB), a functional balance, strength, and walking test, increased by 1.0 on a 0–12 scale, clinically moving these participants from a clinically impaired functional score to a nonimpaired functional score. Overall, the majority of studies examining health outcomes have been primarily focused on weight loss, with some studies examining functional health outcomes in older adults. This is an exciting area of research and could expand into different clinical patient populations and clinical settings with participants from different socio-cultural backgrounds.

USE OF PHYSICAL ACTIVITY WEARABLE MONITORS IN CLINICAL POPULATIONS

The introduction of consumer-WPAMs in trials of clinical populations is increasing. Recently, Moy and colleagues *(27)* examined the long-term effects of an Internet-mediated walking intervention for patients with chronic obstructive pulmonary disease (COPD). In this 12-month randomized control trial of 239 patients with COPD, the health-related quality of life by way of a respiratory questionnaire total score was significantly improved in the intervention group by month 4, but from months 4–12, adherence to the intervention and use of the technology waned, and improvements in health lessened. Hartman et al. *(28)* examined the use of Fitbit One in a group of 54 women at increased risk for breast cancer, and in a 6-month randomized controlled trial reported significant weight loss of 4.4 kg and increases in MVPA of 15 min per day, measured by Actigraph accelerometry. In a smaller sample of 24 cancer survivors, Gell et al. *(29)* examined the utility of Fitbit One after 12 weeks of oncology exercise rehabilitation in a short 4-week trial to maintain PA habits post rehabilitation discharge. In this small efficacy trial, mean MVPA levels were maintained when compared to levels achieved at the end of 12 weeks of exercise-based oncology rehabilitation *(29)*. This study also reported qualitative responses of high satisfaction in using the device and intervention components. Other trials examining the utility of consumer-WPAMs in patients with peripheral vascular disease *(30)*, as well as those examining PA levels post bariatric surgery *(31)*, are starting to be disseminated. With this increased use in clinical populations, exploring mechanisms to provide feedback to a physician team or increasing patient–clinician interaction around behavioral change using consumer-WPAMs would be advantageous.

FUTURE RESEARCH DIRECTIONS FOR WEARABLE PHYSICAL ACTIVITY MONITORING DEVICES

Here we suggest possible avenues that could be pursued to further advance the utility of consumer-WPAMs.

- The consumer-WPAM industry would benefit from reaching out to researchers with expertise in device-based PA assessment to explore improvement in algorithms to increase the precision and accuracy of PA outcomes. This level of advancement in populations of all ages and with different functional and health ailments would increase the market penetration and usefulness for behavioral-based PA intervention and promotion.
- The specific device features that promote behavioral change and adherence can be examined. This would permit individual features that support behavioral change rather than examining the WPAM as a "black box" intervention tool.
- The user characteristics can be examined for long-term adherence to consumer-WPAMs. Current trials are often limited to short interventions.
- The most economical and efficient way to disperse this technology into different subgroups of the population, namely, minorities or those with different socioeconomic status, can be explored.
- Mechanisms to link consumer-WPAM data acquisition to other electronic medical records can be examined to unify data for further clinician use and patient–clinician interaction.

Conclusion

Technological advancement in the wearables market is increasing exponentially, with mobile health and personal health technologies gaining popularity among populations of all ages and within the clinical community. Highlighting this phenomenon, an analysis of PubMed citations by date on the use of the Fitbit WPAM alone revealed that during the period from January 1, 2012, to December 31, 2013, there were 8 publications; between January 1, 2014, and December 1, 2014, there were 53 publications; and between January 1, 2016, and June 20, 2017, there were 135 publications. Current research literature has shown that the validity of consumer-WPAM devices is improving, and their use for modifying PA shows strong promise, with the majority of trials reporting increases in time spent in MVPA or in the number of steps accumulated throughout the day across a multitude of different populations. The rapid evolution of wearable technology may play a role in personalized medicine and increase data metric communication among clinicians, behaviorists, and community programming with the patient or consumer. The future of wearable technology holds great promise to advance the landscape of health and human monitoring and especially to increase the modifiable behavior of PA to benefit public health.

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