Polar Activity Tracking: Background, Feedback and Validity

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TABLE OF CONTENTS

1 Introduction

This white paper describes the background and technology of Polar activity features, feedback to user and scientific validity of Polar activity. Physical activity means moving your body so that energy expenditure gets higher than at rest. Thus, activity tracking is built upon energy expenditure (calorie consumption) assessment. The scientific background of energy expenditure is described in detail in Polar Smart Calories white paper.

Tracking physical activity is an effective way to find out how active one really is throughout the day. Without tracking, people tend to overestimate time spent in vigorous intensities and underestimate sitting and light intensity activities. Polar users can set a goal for daily activity, track daily activity, and get a complete picture of all daily activity at different intensities, including steps and calories, underlining the importance of every move made throughout the day. The user gets an activity goal for each day and guidance for how to reach it. Polar helps to add active breaks to daily routines by reminding the user to get up if they have been sitting for too long. Polar activity tracking rewards the user by giving feedback and showing the health benefits of the activity done.

2 Physiological background

2.1. Physical Activity

Physical activity (PA) is any bodily movement produced by skeletal muscles that requires energy expenditure (WHO 2020). Physical activity can therefore be any movement during leisure time, as part of a person's work, or whilst going from one place to another. Exercise is a form of physical activity that is planned, structured, repetitive, and performed with the goal of improving health or fitness.
All exercise is physical activity, but not all physical activity is exercise.

Physical activity improves our wellbeing; we need it to stay healthy. The health benefits of being physically active are vast. Some benefits are immediate and become larger when PA is regular. Other benefits, such as disease risk reduction and physical function, accrue within days to weeks. PA has been shown to help maintain a healthy body weight, prevent excessive weight gain, maintain healthy bones, muscles, and joints, promote psychological well-being, and reduce the risk of all-cause and cardiovascular mortality, as well as many non-communicable diseases; these include cardiovascular diseases (CDV), stroke, type 2 diabetes (metabolic diseases), some site-specific cancers (namely colon, breast, bladder, lung, endometrium, oesophagus, kidney, stomach cancers), and dementia. PA lowers blood pressure, improves lipoprotein profile, C-reactive protein, and other CVD biomarkers, as well as symptoms of depressive disorders and anxiety. PA enhances insulin sensitivity, feelings of 'energy', well-being, quality of life, and cognitive function. (Physical Activity Guidelines Advisory Committee 2018).

Healthy lifestyle, in general, is a key determinant in the prevention and management of chronic diseases. In addition to being regularly physically active, it includes eating healthy, sleeping enough, and managing stress. These lifestyle factors are also interconnected. For example, being physically active has been shown to improve the quality of sleep. (Physical Activity Guidelines Advisory Committee 2018).

One common way to describe and measure physical activity is through time spent in different intensities depending on their energy expenditure compared to that at rest which is 1 MET (metabolic equivalent of task). Daily activities such as walking at a slow pace or cooking are light intensity activities (less than 3 METs). During moderate intensity activities (3-6 METs), one can talk but not sing. When activity is vigorous (more than 6 METs), one cannot say more than few words without pausing for breath. Intensity is relative, meaning that less fit people require a higher level of effort than more fit people to do the same activity.

International physical activity guidelines (US Department of Health and Human Service 2018, WHO 2020) and other national guidelines establish the minimum amount of physical activity needed to achieve health benefits. The latest guidelines for adults suggest 150-300 minutes per week of moderate-to-vigorous PA (MVPA) or 75-150 minutes of vigorous PA, or an equivalent combination of MVPA. Adults should also do muscle-strengthening activities of moderate or greater intensity that involve all major muscle groups on two or more days a week, as these activities provide additional health benefits. Every move counts and more activity beyond this gives additional health benefits. Inactive individuals can achieve substantial health benefits by increasing their activity level even if they do not reach the target range. There is no specific threshold that must be exceeded before health benefits begin to occur. (US Department of Health and Social Services 2018, WHO 2020, Ekelund et al. 2019). The current consumer-grade wearables enable us to also quantify light intensity PA activities, providing the possibility to accrue evidence for more prescriptive guidelines considering also light activity and sedentary behavior like sitting.

There is compelling evidence that activity monitoring with wearables is an effective behavior change strategy for increasing PA in adults (Physical Activity Guidelines Advisory Committee 2018). Through self-monitoring, people become aware of their current PA behavior (Van Hoye et al. 2015).) In addition to the feedback provided by the tracker, goal setting appears to be an important motivational factor for promoting PA (Bravata et al., 2007; Conroy et al., 2011).

2.2. Sedentary behavior

Everyday physical activity has diminished dramatically in our societies in the past decades. On the other hand, too much time is spent sitting or in other sedentary pursuits. Sedentary behavior (Latin *sedere*, 'to sit') is any waking behavior characterized by a low energy expenditure (equal or less than 1.5 METs), while in a sitting, reclining, or lying posture (Tremblay et al. 2017). If one day is sliced up into periods of different PA intensities, a substantial proportion of our time is taken up by sedentary pursuits, such as sitting or lying down while watching television or mobile phone, sitting while driving, or while travelling, and sitting to study or work at a desk or computer.

Sedentary time (the daily time spent in sedentary behaviors like sitting) often involves prolonged sitting and absence of whole-body movement. Sedentary bouts, i.e., a period of uninterrupted sedentary time, describes prolonged sitting time. Sedentary behavior is independent of physical activity level. One can be an active 'coach potato'. Too much sitting (sedentary behavior) is distinct from too little exercise (inactivity). While sedentary behavior refers to any waking behavior with a low amount of EE in sitting or reclining position, physical inactivity refers to an insufficient amount of PA to meet recommendations (Tremblay, 2017).

In adults, considerable amounts of sedentary behavior are associated with poor health outcomes such as all-cause mortality, CVD mortality and cancer mortality and incidence of CVD, cancer, and type-2 diabetes (WHO 2020, Katzmarzyk et al. 2019, Biswas et al. 2015). Research has shown that both the overall volume of time spent sitting and breaks in sitting have health associations (Owen et al 2010). There are deleterious metabolic consequences of the 6-10 h of sitting to which people can be exposed to daily (Ekelund et al. 2019, Patterson et al. 2018). The relative health risks of sitting are higher in people who are insufficiently active (Biswas et al. 2015).

A recent meta-analysis including objectively measured PA showed that even moderate amount of MVPA (30-45 min per day) attenuates the increased risk of death associated with high sitting amounts (Ekelund et al. 2020). All adults and older adults should aim to do more than the recommended minimum levels of MVPA to help reduce the detrimental effects of high levels of sedentary behavior on health (WHO 2020). Still, in practice, sedentary time can most easily be replaced by light (low) intensity PA. This means taking short breaks, like moving around and taking a short walk. Breaking up sitting with PA has been shown to have a clear effect on metabolism in several shortterm experimental studies by attenuating post-prandial increases in glucose and insulin (Saunders et al. 2018), and triacylglycerol (Loh et al. 2020). The type, intensity, and frequency of PA needed to effectively counteract the detrimental effects of prolonged sitting may differ according to the subjects' characteristics, especially habitual physical activity level (Benatti & Ried-Larsen 2015, Matthews 2016). The benefits of reducing or replacing sedentary time with light intensity activity appear stronger for those who are less active (Keadle 2017).

Sitting and standing are both behaviors at the low end of EE continuum, and neither are ‘physical activities’. By substituting sitting with standing for 6 hours/day, a 65 kg person would expend an additional 54 kcal/day only (Saeidifard et al. 2018). However, sitting differs from standing e.g., in that there is no muscle activity in legs and excessive sitting lowers muscle blood flow. However, the evidence of using standing to replace sitting for health effects is not clear yet (Loh et al. 2020). Prolonged standing can cause musculoskeletal symptoms such as low back pain (Coenen et al. 2017).

How often should sitting then be interrupted? Health benefits have been reported of 1-2 min breaks of light to moderate intensity walking every 20-30 minutes (Dunstan et al. 2012, Peddie et al. 2013). However, in a study by Bhammar et al. (2017), no difference was found between PA breaks performed every 20 or 60 min. More evidence is needed before specific sitting time recommendations appear. They need to be practical, too. Current recommendations state that one should move more and sit less, i.e., to minimize the amount of prolonged sitting (US Department of Health and Human Services, 2018, WHO 2020). Wearables can help in prompting activity breaks just in time. Bond et al. (2014) showed utilizing mobile phones that prompts triggered after 30 and 60 minutes of inactivity were effective at reducing daily sedentary time.

2.3. Steps

Steps counting provides an easy-to-understand metric of human ambulation. Traditional step counters (pedometers) do not take PA intensity into account. Steps are accrued both during habitual physical activity of mainly light intensity as well in exercise sessions. Taking more than 10 000 steps/day has been a rule of thumb. However, it is not known whether this amount is associated with improvements in health compared to setting an alternative goal. Normative data indicates that healthy adults typically take 4 000-18 000 steps/day (Tudor-Locke et al. 2011). Less than 5000 steps/day have been associated with unfavorable indicators of body composition and cardiometabolic risk (Tudor-Locke et al. 2013). A cadence of higher than hundred steps/min has been found to be a reasonable floor value indicative of moderate intensity walking (Tudor-Locke 2018). There have been various results when comparing accelerometer-based and pedometer-based step amounts as well as accelerometer-based results of wrist and waist attachments (Tudor-Locke et al. 2002, 2015). This is probably due to differences in device operation principles, set instrument activity thresholds and attachment sites.

3 Technological background and feedback for the user

Polar has a long history in activity tracking and was one of the first ones to bring out wrist activity tracker in 2007. The first Polar activity tracker was successfully validated in a study of hikers (Brugniaux et al. 2010). Patented filtering and signal processing methods are used to determine the user’s activity intensity from the movements of the wrist and heart rate. Compared to other attachment sites (e.g., hip, waist, or ankle) wrist provides an easy, convenient, and user-friendly attachment site for activity tracking. Polar products have been shown to be feasible in activity tracking in various study populations also over longer periods (Hautala et al. 2012, Henriksen et al. 2020, Jauho et al. 2015, Kinnunen et al. 2012, McNeil et al. 2019, Niemelä et al. 2019a, 2019b, Suorsa et al. 2021, Tanskanen et al. 2011).

Firstly, energy expenditure rate is continuously being assessed by measuring one’s wrist acceleration and heart rate (Fig. 1). User can choose if continuous heart rate tracking is on to enable more accurate energy expenditure throughout the day. Also, subject’s characteristics (age, sex, weight, height, resting and maximal heart rate, and maximal oxygen uptake) are considered in calorie calculations. This has been described more in detail in Smart Calories white paper (Polar Research Center, 2020). Secondly, the estimated energy expenditure as calories is converted to METs, i.e., multiples of resting metabolic rate (1 MET, about 1 kcal/kg/h). Resting metabolic rate depends on age, sex, height, and weight.

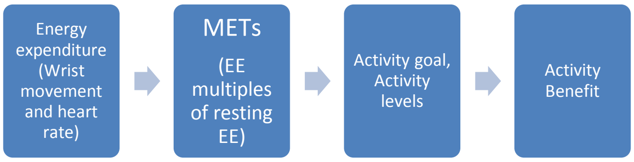

***Figure 1**. How components of Polar activity are calculated*

3.1. Activity intensity levels and active time

Polar classifies METs to intensity levels: low (light), medium (moderate) and high (vigorous) PA, sitting, as well as rest, using MET limits adapted from the literature. METs are analysed in 30 second epochs. (Table 1). The time spent in different activity levels is shown to the user (Figure 2).

***Table 1**. Activity levels, their descriptions and levels that add up active time.*

Level	Description	Active time
Non-wear	Device not worn	
Resting	Sleep and rest, lying down	
Sitting	Sitting and other passive behavior	
Low	Standing work and light household chores	x
Medium	Walking and other moderate activities	x
High	Jogging, running and other intense (vigorous) activities	x

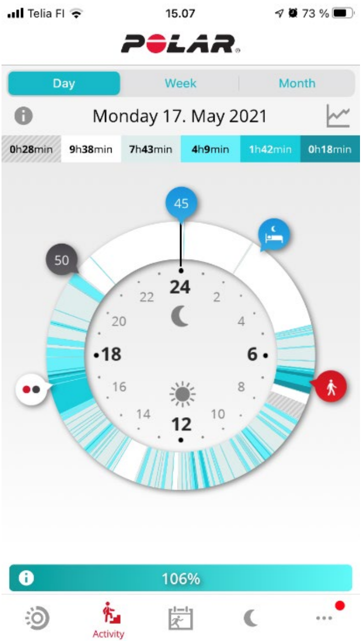

***Figure 2**. Activity day view showing time spent in different intensity levels, timing of activity and sleep and daily goal status.*

3.2. Activity goal and activity guidance

Activity goal is based on the user's personal data, typical daily activity, and activity guidelines. Polar has three options for typical activity (mostly sitting, mostly standing, mostly moving) from which to choose. Choosing the first option is enough to accrue health-enhancing PA, but the other options can be used for challenging oneself. Daily goal status is MET minutes accumulation compared to activity goal, and it is shown as percentages out of 100% (Figure 2). The active time one needs to reach the goal depends on the setting and the intensity of activities. The goal can be met faster with more intense activities, or one can stay active at a slightly more moderate pace throughout the day.

Activity guidance is given as the time a person should be active in low (light) or medium (moderate) or high (vigorous) intensity to reach the daily activity goal. Examples of low (light) intensity activities include cleaning, washing dishes, gardening, playing guitar, baking, slow walking, tai chi. Medium (moderate) intensity activities include golf, circuit training, bowling, moving the lawn, skateboarding, gentle dancing, gentle swimming, and table tennis. High (vigorous) intensity activities include group exercising, rope skipping, basketball, football, playing tennis, and squash (Compendium of Physical Activities).

In daily activity summary total daily energy expenditure (TDEE) is displayed in kcal. TDEE includes both resting EE and activity-based EE. Total daily energy expenditure depends on gender and age being higher in men than in women and declining with age. For middle-aged men it is about 2900 kcal/day and for women 2300 kcal/day (Tooze et al. 2007).

3.3 Inactivity alert

Polar watch spots if one has been inactive for too long during the day and alerts to move. Inactivity alert reminds to get up after 55 minutes of sitting and helps add active breaks to daily routines. It is recommended to stand up and find one's own way to be active; take a short walk, stretch, or do some other light activity to benefit one's health. If no activity is detected in the next five minutes the customer will get an inactivity stamp. One can follow the amount of inactivity stamps in Flow. Besides the many details one gets about their physical activity and all the health benefits that come with it, it is also good to see the periods when one has been still for too long. This way customer can check back on their daily routine and make changes toward a more active life.

3.4 Activity benefit

Activity benefit provides motivation and information on the health and physiological advantages of physical activity and disadvantages of sedentary behavior. It provides textual feedback on the amount and intensity of daily, weekly, and monthly physical activity based on MVPA, and the length of sitting time and interruptions in it. The feedback takes into consideration both total sitting time and interruptions in it.
Examples of feedback to daily physical activity include: '*Not so active day. Try again tomorrow?*'; '*Reasonably active day. This is a good baseline to see long-term health benefits.*'; *'Well done, good amount of activity. This will really benefit your health!*'; '*Impressive! A lot of activity and exercise. This significantly improves both your health and fitness.'.* Examples of sitting behavior feedback include: '*You were sitting for most of the day. Try to break it up with a short walk.*'; '*You were sitting for most of the day. Happy you did not sit too long at a time.*'; '*You only sat a little today. That's great, keep it up!*

Detailed health benefits concerning longer life expectancy, heart health, metabolic health, brain health, stress reduction, mental wellbeing, sleep quality, muscle and bone health, weight control and better body composition are given in Flow web based on the current activity. The feedback is based on international physical activity and sedentary behavior guidelines and backed by scientific evidence. The core idea is that the more active one is, the more benefits they get.

3.5 Steps (Activity steps)

Steps are accumulated when activity is detected. The amount of steps taken is based on movement counting and the rhythm of movement. The steps of all activities are count. This means that steps are accrued from all activity, also including activities without actual stepping, such as cycling and swimming. In 60s-time epochs, the amount and type of movements are registered and transferred to estimation of steps.

Distance shown in association with steps illustrates the distance one would have covered in a day if their PA would be converted to distance. Distance estimation is based on the amount of steps taking into account user's height and stride length. Polar has developed a method for estimating stride length, which considers pace. Stride pace can be tracked from wrist movements. When the number of the steps and stride length are known, the distance can be calculated. Distance shown in association with steps over the day is different from distance tracked during a single exercise session.

Daily activity summaries, steps and calories are available for 3rd parties via Polar Open API.

4 Validity of Polar activity

Energy expenditure assessment, above which Polar's activity features are based on, has been validated against indirect calorimetry in healthy individuals during low-to-high-intensity activities, both daily activities and sport, as described in Smart Calories white paper (Polar Research Center, 2020) and in Gilgen-Ammann et al. 2019. Briefly, Polar Smart Calories are in good agreement with the reference measurement. The best overall results are obtained when both wrist movement (acceleration) and heart rate are used.

Table 3 presents Polar Vantage METs against indirect calorimetry (unpublished) from the same data collection as in Gilgen-Ammann et al. 2019. Resting metabolic rate (RMR) was measured with indirect calorimetry (Cosmed Quark with canopy, Cosmed) completely at rest in a quiet and thermoneutral environment (20°-22° C) in the laboratory for 20 minutes. Energy expenditure of each activity task was measured with indirect calorimetry (Metamax 3B, Cortex). Reference METs were calculated as calorie consumption divided by RMR resulting to average MET per 10 min task.

Table 3. Polar Vantage METs (metabolic equivalent of task) compared to indirect calorimetry in semi-free living physical activity tasks. N=30 subjects.

Activity	Polar MET, mean	Reference MET, mean	Mean bias, METs	Mean absolute % error
All	6.13	5.97	0.16	21.9%
Sitting	1.17	1.19	-0.02	13.6%
Household chores	4.29	3.37	0.92	28.0%
Walking	4.50	3.76	0.74	22.3%
Jogging	8.87	9.80	-0.93	14.6%
Cycling	8.75	7.82	0.93	23.3%
Strength training	6.08	5.28	0.80	25.2%
Floorball	9.49	10.91	-1.41	24.8%

These pre-validation results showed that METs in Polar Vantage are in moderate to good agreement with the reference measurement and the accuracy is activity dependent.

In a study by Henriksen et al. (2019), the MVPA time of 50 persons over one day using Polar M430 was compared to that assessed with Actigraph, a device used widely in research. MVPA time from Polar M430 correlated strongly with that assessed with Actigraph at the waist (R=0.75). The results have been later confirmed with Polar Vantage V (Henriksen et al., unpublished). It should be noted that Actigraph results are dependent on counts thresholds used and it is not a golden standard for PA.

Steps:

Consumer Technology Association guidelines for validating step count measurements of wearables recommends using video recordings of activity performed with two reviewers manually counting steps from the video. Comparing the steps from video to steps from Polar Loop in 20 adults, both men and women, in walking r=0.96 and in running r=0.95 correlation coefficients were achieved at treadmill (unpublished).

In a study by Fokkema et al. (2017) the mean absolute percentage error (MAPE) of Polar Loop steps against hand counting of steps was 1.3 % (3.2 km/h), 8.6% (4.8 km/h) and -0.1% (6.4 km/h) in treadmill walking. Comparable results were obtained in Montes et al. (2020) with steps MAPE <10% in walking (~4.5 km/h) and jogging. Simonsen et al. 2020 showed that validity of step counting (Polar M200, Polar A300) against video recorded steps was higher in walking in the field than walking slow speeds (2-4 km/h) at treadmill.

In comparison to Actigraph worn at the hip, Polar M600 showed good validity for measuring steps on a daily level and a 15-min level but overestimated the number of steps (Degroote et al. 2018).

5 Limitations

In general, wrist-acceleration based activity tracking does not measure accurately all activity modes, such as all lifting and carrying activities or going uphill. However, with continuous heart rate measurement enabled these limitations decreased because internal effort is then taken into account. Wrist-based acceleration measurement cannot distinguish between sitting and standing still.

Polar watch with activity tracking is designed to be worn in the non-dominant wrist. If you wear it on the dominant hand, higher readings will be given because in everyday chores dominant hand will naturally do many more small moves compared to non-dominant hand.

6 Patents

US7728723B2
US8159353B2

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