Using Apple Watch to Estimate Six-Minute Walk Distance

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Overview

With watchOS 7, Apple Watch Series 3 and later provide an estimate of the distance users are able to walk in six minutes, a measurement that may be used in health applications as an overall marker of an individual's cardiovascular fitness and mobility. This paper provides a detailed understanding of how the metric is estimated on Apple Watch, including testing and validation.

Introduction

In-Clinic Six-Minute Walk Test

The six-minute walk test (6MWT) is a simple method of assessing an individual's functional capacity and endurance. First introduced in the early 1980s as a more tolerable and similarly valid and reliable substitute for more rigorous and expensive forms of exercise testing,[1] the 6MWT is most often performed in a clinic setting, where an individual is observed walking up and down a hallway of known length for six minutes. The test result is the total distance walked during the six minutes, referred to as the six-minute walk distance (6MWD). Over the approximately 40 years since its introduction, the test has been well-characterized in many age groups, ethnicities, and states of health and disease. It has been used as a clinical trial endpoint for studying the efficacy of different interventions on disease, as well as a metric for risk stratification across broad populations.[2]

Despite the advantages and utility of the 6MWT, there are drawbacks to the administration and interpretation of the test in routine practice. First, the office or clinic layout must provide an environment—typically a hallway of adequate length (generally 10 to 30 metres) where an individual can walk uninterrupted without disrupting normal clinic workflows. Second, the time and associated costs required for the test can be significant as best practice generally calls for at least one practice test to familiarize the user with the protocol, followed by one hour of rest, and then followed by a second test, which generally yields a more accurate result.[3,4,5,6]

Remotely Administered Six-Minute Walk Test

In a busy clinical setting, administration of a 6MWT may not be practical. Home-administered 6MWTs are strongly correlated with supervised, in-clinic exams and may be a suitable substitute.[7] Measurements of 6MWD using smartphones correlate with in-clinic measurements; however, in a study setting, only 60% of at-home 6MWTs administered and measured with a smartphone were completed.[8] Home testing, while promising, may not be feasible at scale or over long time periods given low participant compliance.

Apple Watch is changing how 6MWD is measured, and it's helping overcome the above practical challenges of both home testing and in-clinic exams. Using data passively collected from Apple Watch Series 3 and later with watchOS 7, users will be able to visualize and share an estimate of their 6MWD. The estimated six-minute walk distance (e6MWD) is based on multimodal sensor signals passively observed over long time periods of a user's normal behaviours, rather than a direct, single point-in-time measurement of a six-minute walking bout. In most cases, an e6MWD will be updated weekly and available for users to view in the Health app on an iPhone paired to their Apple Watch.

Estimated Six-Minute Walk Distance

This paper describes the development and validation of the e6MWD metric. The intended audience is researchers, healthcare providers, and developers who might want to incorporate this metric into their work, as well as customers who would like to know more about the e6MWD metric and how it's collected and validated. Developers can visit developer.apple.com/documentation/healthkit for information on how to access and share health and fitness data—like e6MWD—while maintaining user privacy and control.

Metric Description

The e6MWD metric estimates the distance a user would walk if asked to perform a 6MWT in a proctored setting. This estimate is based on motion and activity data measured during the four weeks preceding the estimate. An example of what a user might see in the Health app on iPhone is shown in Figure 1. The value is reported in metres, and, for most users, will be updated weekly. To generate an e6MWD, Apple Watch requires at least three days with more than eight hours of wear time during normal daily behaviours (for example, waking hours while engaging in light household activities) within the past week, as well as a total of 10 days meeting the eight-hour threshold over the preceding four weeks. An outdoor-walk workout tracked with the Workout app on Apple Watch in the prior week may reduce these requirements.

Apple's HealthKit API allows users to share this information with apps installed on iPhone using Apple's HealthKit API.[9] Each estimate has accompanying metadata that report the device calibration status, which may impact estimate accuracy and is described further in the discussion. These metadata are included when other apps access estimates using the HealthKit API.

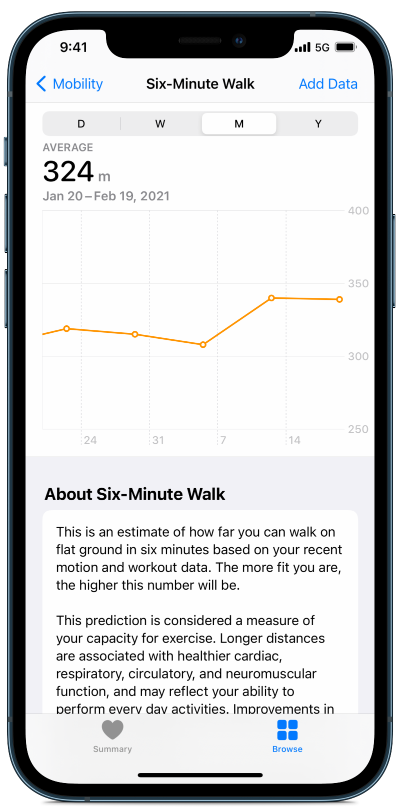

Figure 1: Estimated six-minute walk distance in the Health app in iOS 14

Development

To design and validate the e6MWD metric, Apple collected data from multiple studies, approved by an institutional review board (IRB), involving adults ages 65 and older who live either in the community or in independent living housing and had consented to the collection and use of their data for this purpose. Participants were selected to ensure a diversity of activity levels and functional status; however, all participants resided in Santa Clara Valley, California.

Study participants completed supervised 6MWTs consistent with published guidelines[2] on a linear and flat "out and back" course ranging from 15 to 30 metres in length while wearing Apple Watch Series 4 and carrying an iPhone 8 or later. Protocols for reference 6MWTs for gathering design and validation data were identical. Participants completed up to five 6MWTs over the course of their participation in the studies, with no repeated tests occurring on the same day. Reference test results were verified using additional sensor measurements to ensure that recorded lengths were accurate. Tests that failed these verification steps weren't used in algorithm development.

Participants were then asked to wear their Apple Watch and carry their iPhone during normal day-to-day activities throughout the length of the study. Data from a variety of Apple Watch and iPhone sensors were collected during the study period and used to design the e6MWD algorithm. Inputs into the e6MWD algorithm are sensor data (accelerometer, gyroscope, barometer, and GPS) and other metrics measured by Apple Watch, such as flights climbed, steps, exercise minutes, walking distances, estimated step length, and walking speed.

Participant data was split into design and validation data sets to balance age, gender, and functional level across both sets; the design set was used to develop the e6MWD algorithm. Algorithm performance was determined by comparing e6MWD with participant reference 6MWD results. The validation data set was then used to confirm algorithm performance.

The validity of the e6MWD metric was computed as the mean and standard deviation of errors between the weekly e6MWD estimates and the participant's temporally proximate reference test. The reliability was evaluated by calculating the absolute agreement among measurements and was reported as the intraclass correlation coefficient (ICC). The consistency of the e6MWD metric is expressed as the median and 90th percentile standard deviation of per-subject weekly e6MWD estimates for participants who had at least three estimates. The availability or yield of the e6MWD metric was evaluated as the fraction of total weeks meeting the minimum Apple Watch wear time requirements that yielded estimates and the fraction of participants who received estimates at least 75% of weeks.

Results

Baseline characteristics of the participants whose data were used for design and validation are summarized in Table 1.

Table 1. Participant Characteristics

	Design (*N* = 930)	Validation (*N* = 449)
Gender—number (%)		
Female	578 (62)	263 (59)
Male	349 (38)	184 (41)
Other/Unknown	3 (0)	2 (0)
Age—years*	82 ± 7	78 ± 7
Reference 6MWD—metres (mean ± SD)	375 ± 98	399 ± 102
Length of observation—days (mean ± SD)	389 ± 48	359 ± 67
Comorbidities—number (%)		
Arthritis (hip or knee)	244 (26)	80 (18)
Diabetes	62 (7)	30 (7)
Coronary artery disease	79 (9)	31 (7)
COPD	37 (4)	7 (2)
Assistive-device usage (during 6MWT)—number (%)		
None	718 (77)	395 (88)
Cane	73 (8)	26 (6)
Walker	145 (16)	31 (7)
Other/Unknown	20 (2)	5 (1)
BMI category—number (%)		
Underweight (BMI < 18.5)	13 (1)	2 (0)
Normal weight (18.5 ≤ BMI < 25.0)	379 (40)	158 (35)
Overweight (25.0 ≤ BMI < 30.0)	352 (38)	191 (43)
Obese (BMI ≥ 30.0)	185 (20)	98 (22)

*Participants over the age of 90 didn't have their exact ages recorded to avoid potential reidentification. The mean age was calculated with these participants' ages set to 90 years.

The median and 90th percentile standard deviation of reference 6MWDs per participant were 16 metres and 41 metres, respectively, and the ICC was 0.926 [0.921–0.931 CI]. When restricting to reference tests that passed verification for accuracy, the median and 90th percentile standard deviation was 15 metres and 37 metres, and the ICC was 0.939 [0.934–0.943 CI]. Studies have reported similar ICC values ranging from 0.82 to 0.99.[10]

Table 2. e6MWD Performance

Metric	Description	Design (*N* = 930 participants, 35,890 weeks)	Validation (*N* = 449 participants, 15,223 weeks)
Validity	Error (weekly e6MWD—nearest reference test)—metres (mean ± SD)	1 ± 55	1 ± 51
Reliability	ICC [confidence interval]	0.925 [0.922–0.928]	0.913 [0.909–0.916]
Consistency	SD of e6MWD per user—metres		
	Median	21	17
	90th percentile	40	35
Availability	Percentage of weeks* yielding e6MWD	92	94
	Percentage of subjects who received e6MWD at least 75% of weeks*	89	92

*Weeks with sufficient wear time (that is, those meeting the threshold of at least three days with over eight hours of data in the most recent week).

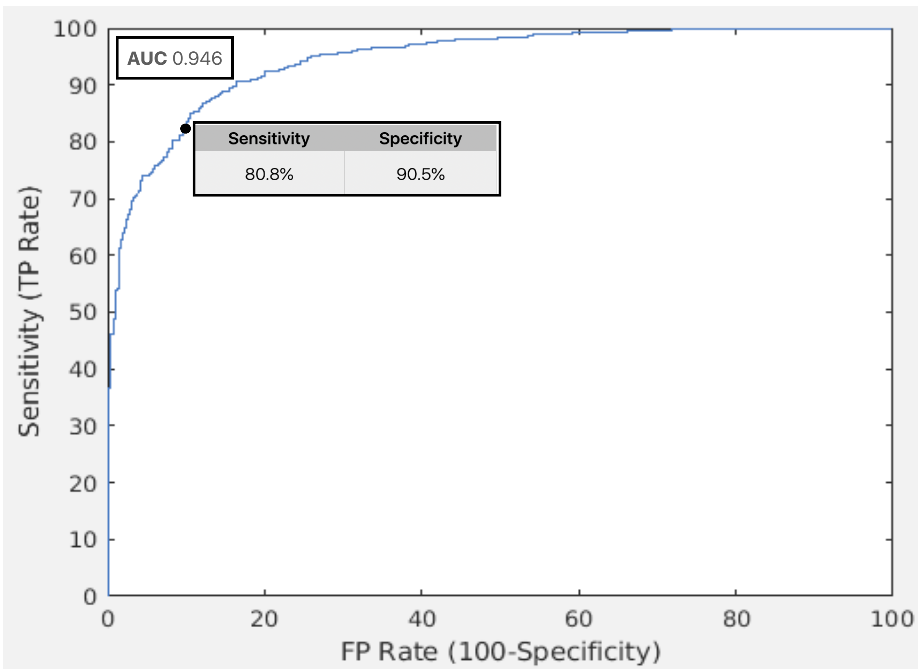

Figure 2: ROC curve, sensitivity, and specificity for e6MWD classification at 360-metre threshold (TP = true positive, FP = false positive)

Table 2 shows algorithm performance for the design and validation data sets. Figure 2 shows the specificity and sensitivity of using e6MWD to classify users with respect to a threshold of 360 metres, along with the corresponding ROC curve (AUC 0.946). Although the 6MWT doesn't yet have widely accepted risk stratification thresholds, several studies have demonstrated relationships between 6MWD (or the corresponding mean walking speed) and health outcomes at similar thresholds.[2]

Discussion

With the release of watchOS 7 and iOS 14, Apple Watch users will be able to view an estimate of their 6MWD in the Health app on their iPhone. Reliable weekly estimation of 6MWD may remove the need for users to perform at-home 6MWTs and, given potentially low compliance with at-home testing, improve long-term monitoring of functional capacity and endurance for at-risk individuals.

The e6MWD described here had comparable accuracy across design and validation data sets, with consistency comparable to those of reference tests in the current study and reported by others.[11] Under normal, unprompted participant behaviour (that is, undirected time spent wearing Apple Watch and normal activity levels), the metric availability was over 90% (see Table 2). For study participants for whom continuous data were available (n = 703), the mean time between estimates was approximately nine days, and 94% of participants had a mean time between estimates of less than two weeks. This suggests that most users should have approximately weekly estimates, particularly in a setting such as a monitored research study where participants are reminded to wear Apple Watch.

Users can optimize yield by wearing a calibrated Apple Watch daily across a representative range of activities. In the absence of this device calibration, the iPhone-based walking speed metric or GPS from both iPhone and Apple Watch can also be used to calibrate this metric. Most users (75%) achieved this calibration within four weeks in the described studies. More information on calibrating Apple Watch can be found at support.apple.com/en-ca/HT204516.

We developed the 6MWD algorithm to provide accurate estimates on low-capacity, potentially at-risk individuals by designing and validating the algorithm in a population of older adults with reference 6MWD within a clinically useful range and in the absence of any single comorbidity. The study populations used for design and validation had a prevalence of diabetes and osteoarthritis in line with those of the similarly aged U.S. population;[12] COPD and coronary artery disease may have been underweighted relative to expected prevalence.[13] Assistive-device usage during reference testing overall approximated that of the U.S. population; although cane usage may have been slightly underrepresented.[14]

Clinical applications of 6WMT (such as risk stratification and therapeutic response measurement) typically use distances less than 500 metres across a variety of conditions, including heart failure,[15] pulmonary artery hypertension,[16] chronic obstructive pulmonary disease,[17] and cancer.[8] Based on their level of fitness or age, many users may consistently have values of 500 metres, the maximum estimate supported by this algorithm.

While equations predicting 6MWD are typically based on an individual's height, weight, age, and potentially other characteristics,[18,19] the e6MWD described here is an individualized estimation based on direct, sensor derived measurements; comparing e6MWD with reference equation-based predictions to inform a "percentage of expected" may hold value beyond that of the e6MWD value in isolation.[20] The absolute e6MWD may be useful for risk stratification in older adults. Yazdanyar et al. found that among community-dwelling older adults, a 6MWD of less than 338 metres was associated with an increased risk of all-cause mortality.[2.]

The approach and results presented aren't without limitations. The data used were from proctored 6MWTs using different course lengths to develop the e6MWD. While some reports suggest that course length has a statistically significant effect on 6MWD,[21] most studies show that this difference isn't clinically relevant and that consistent course layout (for example, oval compared with "out and back") has more impact on 6MWD.[22,23] Increased variability in low-capacity users was present, particularly those using walkers (data not shown). Racial and ethnic diversity in the study population didn't approximate the U.S. population; however, prior studies in similarly aged populations haven't found independent differences in 6MWD based on race or ethnicity and haven't recommended adjusting expected values based on these factors.[24]

The studies used for design and validation of the 6MWD algorithm weren't designed to capture significant changes in participants' 6MWD over the course of observation; however, changes based on health events, natural aging, or progression of comorbidities may have occurred. For clinic-based measurements of 6MWD, "clinically significant" change may range from approximately 15 to 50 metres depending on any underlying pathology affecting the population being studied.[4,25] Future work demonstrating the ability to detect change on this scale may enable researchers and developers to use this metric for monitoring the course of disease or recovery from a health event.

Conclusions

Apple Watch can provide a weekly estimate of 6MWD, giving users a new metric to measure and monitor multiple dimensions of their health over time. This data may also be useful to researchers and healthcare providers. Wearing a calibrated Apple Watch across a range of activities that are representative of a user's capacity is the best way to assure that an accurate estimate is recorded each week.

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