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ASSESSMENT OF LIFESTYLE TRACKERS FOR TOTAL EXPOSURE HEALTH

**Jeffrey Miller, Diane Krause, Betsy Smither, Ken Shelton, Ann Gonzalez, Jennifer Tucker
Oak Ridge Associated Universities**

**Misa Okamoto
Cape Fox Federal Integrators, LLC**

**Robert Bradford
UES, Inc.**

**Logan Stec Hyder
VATC LLC**

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**AIR FORCE RESEARCH LABORATORY
711TH HUMAN PERFORMANCE WING,
AIRMAN SYSTEMS DIRECTORATE,
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE**

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DIRK P. YAMAMOTO, DR-III
Product Development Branch
Airman Biosciences Division
Airman Systems Directorate
711th Human Performance Wing

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Digitally signed by
WILLIAMS.LOGAN.ANDREW.1273597634
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Date: 2021.09.07 14:47:15 -04'00'

LOGAN A. WILLIAMS, DR-III
Human Performance Product Area Lead
Operational Product Section
Product Development Branch
Airman Biosciences Division

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1.0 Summary

Lifestyle and fitness trackers have become prevalent pieces of wearable technology due to their myriad of measurement capabilities, designs, and features that lend themselves well to a variety of professional fields and individual user levels. The widespread applicability and access have driven their popularity over the last decade. The United States Air Force (USAF) requested that Oak Ridge Associated Universities (ORAU) and UES, Inc. conduct a research project to identify and compare existing tools that could be utilized for total exposure health studies that track lifestyle behaviors. After narrowing the tracker search down to only smartwatches—over rings, smart clothing, and other items—for their ease of use, light weight, and lengthy feature list, ORAU conducted a literature review and market analysis to look at what existing devices would be suitable. By breaking down their extensive and varying capabilities across hundreds of different criteria—from battery life to specific activity tracking measures to data transfer and security—a couple dozen specifications stood out as being particularly important and necessary that allow for further differentiation and identification of the best, most suitable wearable devices.

This list was further narrowed to six high-performing and widely useful smartwatches on the market in fall of 2019 and early winter 2020: two Garmin devices, the Apple Watch, a Polar, a Samsung, and a Fitbit. Selection of these devices led to creation of a matrix tool (Compare Smartwatches Tool). This extensive tool allows for easy filtering of and searching through criteria to customize a list based on the particular features or specifications deemed important to the user. Several pre-filtered views were built into the tool to assist with easy prioritization of certain aspects of the devices, such as human performance measures. Due to a user's varying needs and priorities, one specific device is not recommended across the board. The Compare Smartwatches Tool provides the user the comprehensive ability to identify the most applicable smartwatch for their purpose.

It is worth noting that once a device is chosen, the decision to consistently wear it rests with the individual user and their preferences, personality, and concerns. The most effective way to approach device data is through 24-hour wear, but certain career fields and environments and concerns over privacy or confidentiality will affect that decision.

2.0 Introduction

2.1 Definition and Market Space

Lifestyle tracking devices, sometimes called fitness or activity trackers, are wearable technological devices designed to track and measure various aspects of an individual's health, fitness, activity, and routine. They can vary from popular devices available to the general person such as a Fitbit or Apple Watch to more specialized devices utilized primarily in the medical community. These types of wearable tracking devices have increased in sophistication in recent years, moving beyond basic step-counting to complex computing and analysis—detecting and measuring heart rate, atrial fibrillation, skin temperature fluctuations, sleep/wake cycles, providing global positioning system (GPS)-routing, playing music, and more. As that sophistication grows, so does their apparent popularity around the United States (U.S.) and the world. WageWorks estimates that wearable technology will reach over 243 million devices and \$29 billion in sales by 2022, rising to \$111 billion by 2025.¹ This includes wristbands and watches, jewelry (rings, necklaces, etc.), smart clothing (sensor jackets, workout clothing, etc.), and eyeglasses.

It seems clear that market opportunities are only growing for this sector. Tech site [wearable.com](#) reported on a market analysis from Gartner that predicted wearable product sales will reach \$52 billion in 2020, a rise of 27 percent (%) over 2019.²

The 37th WT | Wearable Technologies Conference will take place in San Francisco in July 2020. Billed as the “world’s biggest wearable technologies conference series,” the 2019 event featured presenters from healthcare companies, software and hardware developers, marketing and business development, legal, and other related areas.³

2.1.1. Purposes

Although many users rely on their wearable devices as a way to maintain personal accountability for wellness or fitness interests, the medical field is open to the use of gathered data in medical records. Fitbit, Apple, and Samsung are involved in the United States Food and Drug Administration’s (FDA) Software Pre-certification program that aims to develop “a future regulatory model” for oversight of “software-based medical devices developed by manufacturers who have demonstrated a robust culture of quality and organizational excellence, and who are committed to monitoring real-world performance of their products once they reach the U.S. market.”⁴

Fitbit has teamed with Bristol-Myers Squibb-Pfizer to seek FDA approval for atrial fibrillation detection software⁵ and the Apple Watch Series 4 and 5 offer an electrocardiogram (ECG) app that can be used to check for atrial fibrillation.⁶ According to tech site [wearable.com](#), a number of manufacturers are working to develop convenient blood pressure monitoring⁷ and it seems to be only a matter of time before pulse oximeter sensors (measuring oxygen saturation in the blood) can be used to identify sleep apnea in wearers.⁸

Wearables have become popular for tracking wellness or sport and fitness activities. Professional sporting organizations, like the Fédération Internationale de Football Association (FIFA), have introduced standards and rules for the use of electronic performance and tracking systems.⁹ The National Football League Players Association (NFLPA) announced in 2017 that wearable WHOOP was the officially licensed recovery wearable of the NFLPA.¹⁰ Other teams or organizations use sensors embedded in or on clothing.¹¹ Several wearable manufacturers offer team-training packages, sometimes through an affiliate, allowing a coach to view a dashboard of player statistics.

Additional wearables features that can be used in everyday life, but do not necessarily fall into the health and fitness category, include playing music and podcasts, checking emails and text messages, social media engagement, answering phone calls, and storing payment information on the device. Led by all-around smartwatch devices like the Apple Watch or Samsung’s Galaxy Watch Active2, these lifestyle trackers have essentially become phones attached to one’s wrist, in addition to all the fitness-monitoring capabilities.

2.1.2. Interested Parties

Numerous individuals, groups, and industries have shown an interest in using or exploiting fitness tracker data. These include the everyday consumer user, healthcare providers, healthcare researchers, and the insurance industry.

The average person is most familiar with devices that monitor their own daily activities. People enjoy being able to self-monitor their vital signs and activity levels for a variety of reasons. These range from a senior citizen who wants to count their steps throughout the day to the extremely health-conscious who want to monitor pulse oximetry and use GPS-mapping to track triathlon training. Most consumers fall somewhere between these extremes, but the takeaway should be that there is a device for every user.

The potential medical benefits and health-based features have garnered the interest of the professional medical community, members of whom see these devices as useful in creating a more personalized medical experience. By being able to track changes in everyday vital signs or monitor the physical activity of patients, a physician can customize treatment plans based on daily habits. Instant patient access to this data allows patients to identify changes in their normal routines and health information quickly and provides daily feedback about their progress toward activity goals.

The healthcare and academic research sectors are eager to learn just how accurate wearable trackers are, the validity of measurements taken, and their effectiveness in influencing or changing personal behavior. Rapid technological improvements, device cost, and publication lag work against researchers, but as device utility and potential importance increases, the literature on the topic will become more robust.

Some life insurance companies, in a medically-adjacent business sector, have already begun offering discounts to customers in exchange for sharing their tracker data with the company and it's possible health insurance groups and others may pursue a similar path.¹² National Public Radio (NPR) reported that some insurance companies are offering cash rewards as well as free or discounted trackers to plan participants.¹³ Being able to track which of their clients are exercising frequently versus leading sedentary lives could lead insurance agencies to begin offering a range of rates or services depending on lifestyle, justifying those decisions based on perceived risk from the insured's choices.

In an opinion piece in the Journal of the American Medical Association (JAMA), the authors note four concerns regarding use of wearable tracker data by insurance companies: (1) although trackers are currently used as incentives, there are no rules preventing the companies from penalizing those who do not use trackers or who report less-healthy data; (2) data quality may vary widely depending on device and, at this time, few devices have been clinically validated; (3) health care disparities may be exacerbated by device cost, with low-income customers losing out on both the health benefits of a tracker as well as any financial incentives offered by the insurance company; and (4) the authors note that data collected by wearable devices is not protected by the Health Insurance Portability and Accountability Act of 1996 (HIPAA) and caution that aggregations of personal data can be a source of income for device and app manufacturers and developers.¹⁴ An additional caution is the possibility of fraud through data falsification by those seeking lower rates or other benefits.

2.2 Summary of Current Trends, Technology Improvements, & Limitations

2.2.1. Device Types

Although the lifestyle tracker market is dominated by watch-like wristbands and smartwatches, other wearables include rings and other jewelry items, wristbands without interactive features (accessible only through an app), smart clothing, and smart eyeglasses.

2.2.1.1 Jewelry

Lifestyle jewelry includes the Motiv, Oura, and blinq rings and Bellabeat products that can be worn as necklaces, brooch-style clip-ons, or bracelets. Motiv rings can count steps, distance, and active minutes, feature a heart rate sensor, and can tell when the wearer is asleep. Access to the data is provided through a smartphone app – as long as one has an iPhone, Samsung Galaxy or Note, or Google Pixel. The Motiv ring's battery lasts for about 3 days.¹⁵

Another fitness ring, the Oura, also features activity tracking and a heart rate sensor, but provides in-depth information on sleep and recovery as well as body temperature. Oura's data is accessible through their Moment app, which is available for Android and iOS.¹⁶

The blinq ring is best described as a fashion-conscious smart ring rather than a true fitness tracker. Although the ring counts steps, distance, and calories burned (accessible through Google Fit or Apple Health) and has limited waterproofing, it appears that its primary use is in conjunction with a smartphone to receive app alerts. The ring also has a panic button feature, allowing the wearer to send a location SMS message to contacts or social networks.¹⁷

Bellabeat is a smart jewelry company that offers several styles of fitness tracker (as well as smart water bottles) that are “optimized for women’s health.” The trackers are water-resistant, powered by watch batteries, and most can be worn as a bracelet, necklace, or clip. They track activity, sleep, and reproductive cycle as well as evaluating stress sensitivity.¹⁸ Access to data is through a smartphone app (Android and iOS).¹⁹

2.2.1.2 Wristbands

At least two companies manufacture tracking wristbands without a display screen. Moov offers two types of bands that provide audible coaching through smartphone or tablet-connected headphones based on either motion or heart rate. The motion band is waterproof and can be used to track stroke rate and distance in a pool. The coaching provides encouragement, offers form correction, and tips to improve one’s performance. The bands also track sleep. Statistics are accessed through an app available in Google Play and Apple Store.²⁰

Another popular fitness band is the WHOOP Strap. Rather than tracking steps, this wristband uses heart rate variability, resting heart rate, and sleep to calculate a recovery score. WHOOP provides a strain score based on cardiovascular load over the day and evaluates duration and quality of sleep, in addition to providing a recommended duration for the upcoming night.²¹

2.2.1.3 Smart Clothing

Smart clothing runs the gamut from pods that fit into specially designed workout clothing, sensor-enhanced denim jackets, socks designed to monitor diabetic foot injury, and even smart yoga pants that assist a yogini practicing on his or her own.²² These items of clothing can track sleep, heart rate, and breathing, identify increases in temperature indicative of inflammation, and use smartphone connections to play music and provide GPS directions. Some smart clothing has incorporated monetary features, allowing the wearer to pay for items at the cash register, much like touch-to-pay credit cards. Other clothes monitor environmental factors, such as solar UV rays and outside temperature.²²

2.2.1.4 Smart Glasses

Smart glasses seem to be primarily an information-delivery, augmented reality (AR) device rather than a stand-alone tracker. Used in conjunction with a smartphone app, information from the phone, including alerts/notifications, GPS directions, sensor data, and customized training screens, is shown in the glasses display.²³

2.2.2. What They Track

Most smartwatch-style trackers today gather data related to physical activity, including steps, distance, and vertical elevation gain/stairs, as well as heart rate. Waterproof models often provide swim tracking, including laps/lengths, duration, pace, and heart rate. Many also track sleep and menstrual cycle. Some models claim to detect stress (based on heart rate variability) and may coach the wearer through breathing exercises. Several models offer energy monitoring or recovery status, and some recommend future training intensities.

Location can be tracked through use of the GPS feature, if available and activated. However, the use of the GPS feature significantly reduces the battery life of the smartwatch, requiring more frequent battery charging sessions. Some Polar models measure running power without the use of a foot pod or sensor.

The Apple Watch Series 5 is capable of generating an ECG similar to a single-lead electrocardiogram with the ECG app. Apple also offers a Noise app that senses decibel levels and warns the wearer of potentially dangerous exposure.²⁴

Activity measurements are often time-linked, so users can track how long they are participating in a particular activity. Other variables, such as heart rate and training metrics, are tracked to allow users to see if their session was productive for their goals.

Trackers that monitor sleep often provide data related to number of waking periods, sleep movement, sleep state (e.g., rapid-eye-movement [REM]), and respiration).

Specialized environmental sensors include temperature and ultraviolet (UV) ray exposure. These sensors can warn the user when temperatures might have an adverse effect on activity or health and of excessive UV exposure.

2.2.3. Limitations

Despite the many functions of lifestyle trackers and their increasing abilities, they are not without limitations. Several identified challenges include proprietary operating systems and software that does not cross-communicate, battery life, security concerns, and accurate tracking.

A major limitation in wearables is the separate ecosystems of products. The major companies (Apple, Fitbit, Garmin, Polar, and Samsung) have invested significant funds into proprietary operating systems. This can be challenging for third-party app developers and may hamper the likelihood of easy data transfer between diverse wearables and a patient's electronic health record.²⁵

Additionally, companies have developed their own proprietary algorithms to process data gathered by devices. The exact nature and validity of these algorithms is a concern for researchers who may use the device as an intervention in behavior change strategy studies or wish to compare multiple devices. There also exists the potential for "discontinuity in [research] data over time" as programming is changed behind closed doors.²⁶

A second challenge faced by researchers using wearable devices is battery life. The need to remove the wearable to recharge can affect the validity of longitudinal research using trackers.²⁶ Battery life can be a real concern for individuals without easy access to electricity, including service members in the field.

This leads, however, into a third limitation, that of security. The lack of security in Bluetooth connections and proprietary operating systems of the devices "cannot be easily integrated in tactically secure systems," making device use potentially problematic for secure operations, whether military or in the medical arena.²⁷ Most wearable technologies transmit a unique code at regular intervals to track the wearer and communicate with one's phone or other device. If this code is not randomized adequately, it can be captured and linked to a specific time and location.²⁸ By intentionally creating devices that link seamlessly to others like this, it opens up the door for interception and exploitation. This is a recognized concern and there is a subset of wearables literature related to the topic. Researchers presented a hybrid real-time cryptography algorithm to protect cloud-based healthcare services and monitoring devices at an Institute of Electrical and Electronics Engineers (IEEE) conference in 2017. Experimental results indicated that the algorithm provided "a high level of security" for "lightweight wearable medical

devices.”²⁹ Other researchers have developed a wearable fingerprinting technique focusing on Bluetooth protocol using machine learning algorithms.³⁰

Geotracking, or the identification of a person’s location through data from a GPS-enabled device, is another security concern with applicability to the military context. Geotracking is popular in the fitness community, as it provides individuals the ability to track their exercise, from running to swimming to hiking trails.³¹ However, national security could be compromised if data from service members in the military and intelligence communities, whose locations may be considered sensitive information, are shared publicly through geotracking on social fitness sites.

2.3 Lifestyle Trackers in the Research Community

While these wearable devices are still relatively new, there has been a sharp increase in the number and depth of research studies examining them. However, because of the speed of technological increase, publication lag may affect the usefulness of accuracy and validity of studies for specific devices, and many more advanced models may not be evaluated at all.

A snapshot of clinical trial research in the United States can be found at the National Library of Medicine’s ClinicalTrials.gov website. At the time of writing, this site listed 331 studies (of all kinds) in the U.S. using Fitbit devices. Other devices used include Apple Watch (26 results) and Garmin devices (21 results).

Examples of validation-type research include:

Example One:³²

Researchers tested Fitbit Flex (relatively unsophisticated fitness tracker; no display screen and limited capabilities), to include:

- Validity of measuring sedentary behavior and physical activity
- Comparison with ActiGraph GT3X+
- 7 consecutive free-living days each
- Noted Flex was “comparatively accurate” for sedentary behavior, overestimated moderate-vigorous physical activity

Example Two:³³

Researchers tested these devices: Samsung Gear 2, Fitbit Surge, Polar A360, Garmin Vivosmart HR+, Scosche Rhythm+, and Leaf Health Tracker. Research examined:

- Comparison of step count and heart rate in free motion and on treadmill
- Comparison of heart rate measurements with Polar T31 monitor
- Step count – mean of two manual counters
- 5-minute intervals, matching pace, “devices worn simultaneously in randomized configurations”

In another study, researchers compared the accuracy of “free-living total energy expenditure” over 10 days using Fitbit Surge and a research-grade accelerometer, with baseline expenditure determined using

doubly-labelled water (DLW) and daily urine samples. Fitbit tended to underestimate calories burned through physical activity while the research-grade tool numbers were “near identical” to DLW measurements.³⁴

Other research has focused on behavior change, particularly whether or not wearing devices prompts individuals to change their routine, exercise more, or simply pay closer attention to their health and wellness.

2.4 Feasibility of Health Surveillance/Trends

Researchers compared the U.S. Fitbit Health and Activity Index (<https://www.fitbit.com/activity-index>)³⁵ reported data with similar data points in the Centers for Disease Control and Prevention’s (CDC) Behavioral Risk Factor Surveillance System (BRFSS); <https://www.cdc.gov/brfss/>).³⁶ Fitbit indicators related to steps and active minutes showed a poor association with oxygen uptake (VO₂) and a fair association with vigorous activity. Fitbit’s resting heart rate indicator showed a poor association with VO₂ and total physical activity, and a fair association with vigorous activity. The Fitbit indicator showed a fair association with body mass index (BMI).³⁷

A report by the Naval Health Research Center³⁸ reviewing literature between 2009–2016 found that reliability and validity of wearable activity trackers varied substantially by task, measure, and device. Their assessment found increases in activity occurring for the populations monitored for programs that contained a structured, behavioral intervention, educational, or feedback component.

While increases in activity may be encouraged by the use of wearable trackers, there is a question as to the feasibility of using these trackers in situations more serious than simple activity tracking. Are they accurate enough and reliable enough to be used for epidemiological monitoring? This is an ongoing dilemma. Some devices show high accuracy in evaluation research related to steps counting. Others tend to underestimate or overestimate measurements, particularly related to energy expenditure (calories burned).

Other research has shown poor associations in intra-device measurements, like steps, active minutes, and heart rate, and certain health statistics such as maximal oxygen update (VO₂ max). This suggests that some measures may be less reliable than desired for monitoring one’s health. However, other variables perform better; stronger (albeit not “strong”) associations have been shown with vigorous activity and BMI. This indicates that there may be some health applications, even if they are not perfectly accurate in all measures. The more complicated the measurement, the less precise it may be, so the feasibility of using wearable technology depends greatly on the data under observation and the devices to which the user has access.

User preferences for wearable lifestyle trackers vary as widely as the available features on these products. Deciding factors may include the sensor and technology features reviewed above, aesthetic choices like design, and perceived utility. Each user is different, with unique motivations for pursuing the purchase of a wearable tracker. Thus, whether or not an individual, organization, or researcher finds utility in the tracker will depend greatly on their motivation. As Burbach et al. note, the user profile matters.³⁹

Successive generations of trackers are likely to incorporate improved technology with higher degrees of measurement accuracy. Research on the most cutting-edge devices is either non-existent or still ongoing. Prices on basic models may fall further, putting tracker use within reach of more users. It is likely that the productive use of wearable trackers in health surveillance will increase as technology improves and their use becomes more widespread.

2.5 Suitability for Different Lifestyles

2.5.1. Career Fields

While the usage of these wearable devices would undoubtedly be a helpful research tool and health tracker, there are certain career fields within the U.S. Air Force where wearable devices would likely be problematic for personnel. When factoring in (1) security risks, (2) personnel that already wear an official watch for other purposes, or (3) safety concerns such as bulkiness, there are subsets of Air Force members who would likely have limited ability to participate in a lifestyle tracker initiative due to their career field and job requirements.

On the security front, career fields related to intelligence would almost certainly need to take special precautions. Others, such as pilots, may fall into that category as well. While these devices may include strong security measures, the risks may simply be too great and outweigh the benefits of the technology. There are always unintended consequences that are overlooked; for example, the GPS-tracking scandal with Strava in 2017 that accidentally revealed secret military locations and personnel.⁴⁰ That incident created a security vulnerability, but it highlights the problems with utilizing external technology in secure areas and the potential for exploitation.

However, it is not just a security concern that may limit the utility of wearable devices in certain career paths. Certain members of the air crew are already issued Garmin watches that require precise syncing with one another to accomplish their jobs. Adding a second watch for fitness or lifestyle tracking would be redundant, potentially disadvantageous to what they are working on, and likely be rejected by the individual, as well. They may elect to use it in their spare time, but not while on duty.

Finally, there are certain jobs, such as those on the flight line, where the mere presence of the device on their wrist could pose a safety problem. Smartwatches can be distracting, a concern demonstrated through research on their usage, and distraction while executing a dangerous task would increase the risk. Additionally, adding bulk to the apparel of those on the flight line may be unallowable. These jobs limit bulkiness in the outfits of their members, having them stripped down as much as possible on the extraneous items like jewelry and watches for matters of safety. This would likely limit the feasibility of using wearable technology, unless they were to only wear it while off-duty.

That said, there are many other positions for which lifestyle trackers could likely be successfully implemented. Air Force personnel in career fields like the Judge Advocate General (JAG) Corp, medical, finance, logistics, civil engineering, and others could benefit from these lifestyle devices. While these fields are more restricted in scope than simply applying evenly across the entire Air Force, the lifestyle tracker initiatives would still be able to provide valuable information, particularly in training, which could be applicable—in limited capacities—elsewhere.

The military encompasses many different lifestyles and career paths, both domestically and around the globe. That diversity of job means that lifestyle tracker usage almost certainly will not be applied evenly across the entire military branch. There will inevitably be sectors that either cannot wear one due to security or physical reasons, or that it would be unwise to wear one due to its superfluous role or distracting nature while performing dangerous tasks. However, there are many careers for which the trackers would be suitable.

2.5.2. Environments & 24-Hour/Off-Duty Monitoring

One other factor that will affect the suitability of using lifestyle trackers will be the environment in which the user is living and working. For the data collection to have its maximum effectiveness and accuracy, users will have to wear it as near to 24 hours per day as possible, which may further limit its suitability at

the individual level. While overseas, there may be difficulties in syncing the device to local time, and it would be very difficult to police its usage in off-duty times or to make its wear completely mandatory. At the end of the day, a monitoring program is limited by the willingness of individuals to wear—or simply remembering to wear—the device all the time, even during off-hours.

Further, there are likely scenarios with problematic or unpredictable weather, environments that are especially wet or dusty—both of which have the potential to get inside and impact the trackers' electronic system—or locales and assignments without necessary and timely access to electrical power. While most trackers are designed to be quite durable in unusual environments, that does not mean they are impervious. The grand majority of lifestyle tracking devices were built and planned with the average person in mind, meaning that while they can manage in hazardous conditions, that is not their primary purpose, and sustained stress on their systems could increase the risk of malfunction or inaccurate recording. As one example, devices frequently are water-resistant to a certain depth or length of time under the water's surface, usually designed for people wanting to track their swimming workouts. Yet, that does not mean they are water-proof or that they can be held under longer or to deeper depths. It is crucial to consider the device's uses and what it can reasonably manage and for how long.

2.6. Other Barriers to Adoption

Other than what has been previously discussed—from career path to environmental factors—the other barrier to be considered takes place at the individual user level. Individuals must be convinced of the device's usefulness, and provided a way to understand and use the information collected.

There may be certain members who are particularly keen on using a tracker because they are in a career field that requires an extraordinary level of fitness, they are fitness enthusiasts who are already tracking their workouts, because they could use the extra motivation of a lifestyle tracker to help them get in shape to pass required fitness tests that they might have struggled with in the past, or it would help them succeed in a mandated program to lose weight. These individuals would likely possess the fewest barriers to adoption, but outside of those groups, there may be some longer-term sustainability issues that hamper the initiative's usefulness.

2.6.1. Sustainability of Use

Research has shown that, once obtained, devices may not be worn with regularity after the first few months of use. A 2016 review article by Wright, et al., cites a 2014 industry report in which 33% of respondents stopped device use within 6 months, with just over 40% still using their fitness tracking device after 24 months.²⁶ This is because the motivational dynamics of wearables use is heavily dependent on the psychology of the user. While a variety of behavior change techniques including self-regulation, persuasion, and changes to the environment are used by wearable activity monitor software and associated apps, the techniques and tools vary in effectiveness according to personal preferences and lifestyles.⁴¹

Burbach et al., described how perceptions related to four factors—privacy, usefulness, accuracy, and motivation—influence the use of tracking devices by different user types. The authors surveyed over 400 participants using a web-based questionnaire and identified three groups: data protectors, benefit maximizers, and facts enthusiasts. For data protectors, privacy was the most important attribute of tracker use. Benefits maximizers were most interested in the utility of the device. Facts enthusiasts were closely interested in both motivational design and the accuracy of the data.³⁹ But perceptions of privacy, usefulness, accuracy, and motivation all directly impacted individual long-term usage of the device.

However, while there are barriers for sustained use as noted here, there are certain social factors, such as connectivity, communication, and competition that can impact the user's experience, to be considered as well.

2.7. Social Issues

2.7.1. Connectivity

One popular feature of many fitness tracking wearables is the social aspect, allowing the wearer to connect with other users and the broader fitness community through connections via apps for wearables. Many companies promote this connectivity as a means to generate friendly competition among friends and family. Additionally, if a new purchaser is unsure which device to buy, the ability to compete against (or support) a peer group may be a deciding factor. Users can often access public workouts, compare their basic statistics to others, and communicate with one another within the wearable app.

These features are more common on devices that are easily accessible to the general public than more secure networks, but the ability to share and communicate with a doctor's office or within a secure military system could be beneficial.

2.7.2. Technical Compatibility

As discussed previously, technical compatibility is a limitation of fitness trackers. Most companies use proprietary operating systems and technology that may struggle to integrate with different operating systems or systems that require high-level security.

The popular Apple Watch is designed specifically to integrate seamlessly into the Apple operating systems, which are run exclusively on Apple products. Mac computers, iPhones, iPads, and other Apple products are highly compatible with the watch. However, when trying to use Apple Watch with Android operating system (OS), many of the most popular and often-used features simply will not work. The user can still make use of the watch and some basic capabilities, but a lot of functionality is lost due to its lack of compatibility. Socially, this may look like the inability to share progress, compete with friends online, and motivate one another through the watch's app on the iPhone. While Apple has a reputation for its strictly-guarded and distinct proprietary systems—many would argue to a fault—other companies are not that far behind in restricting compatibility.

When it comes to social aspects of the devices, this may pose a minor annoyance for the average user. However, as integration drifts into issues of security, when institutions are attempting to take advantage of the fitness tracker's abilities, understanding the security and ensuring its compatibility with their secure system becomes paramount.

2.8. Security/Ethical Consideration

2.8.1. Privacy

An important and increasingly common consideration surrounding lifestyle tracker use is that of privacy. In past years, when trackers acted as electronic pedometers with perhaps a calories burned estimate thrown in, privacy was less critical. With increasing sophistication, the number of measurements grew, and device apps now allow a user to track personal health information in conjunction with physical activity.³⁹

Fitness trackers can include gyroscopes, heart rate sensors, thermometers, GPS location monitors, and a variety of other sensors. When sensor data is combined with a specific location, this can create security vulnerabilities, both on the individual level and for companies or organizations.

In 2017, the company Strava (a social network for athletes with wearable fitness trackers) released user activity online, publishing heat maps of its users showing popular routes for exercise like hiking, running, and biking. However, it was not long before international security experts began to notice connections between those heat maps and known military operational bases.⁴² They determined the routes shown were used by military service members and inadvertently revealed the locations of several bases and facilities in potentially sensitive parts of the world. This put many at risk, allowing for the potential to track individuals, military routes and patterns, and more. The heat map incident re-emphasized the need for service members to be cautious about what data to share via wearable electronic devices.⁴³ As a result, the Pentagon ultimately banned deployed service members from wearing such fitness devices when geolocation services were enabled.⁴⁴

Other privacy concerns arise from the transmission of data. Most devices use Bluetooth LE, sometimes called Bluetooth Smart, a low energy transfer technology that can send the data from the device itself to a smartphone or computer. Best practice would dictate that this connection be secure and resistant to eavesdropping attacks.⁴⁵ This generally works by having the wearable transmit a unique code at regular intervals to track the individual and still communicate with the phone. If this code is not randomized, or not randomized frequently enough, it can be captured and then linked to a time and GPS location. Bluetooth connections are inherently a less secure means of transmission, having been designed to easily link devices for synchronization, but this feature also opens the door for interception and exploitation.

In 2018, Tahir, et al., explored the use of novel Integrated Circuit Metric (ICMetric) technology to facilitate secure data transfer. ICMetric technology can use a tracker's gyroscope and accelerometer sensors to generate an identification, which allows secure transfer. The experiment and simulation results showed high levels of security with low resource demands.⁴⁶

Additional sensor-activated authentication includes using a "force sensor activated authentication method" as a way to bolster password protection.⁴⁷

Privacy requires vigilance on the part of users and prioritization on the part of the technology companies, which will likely come about as a result of legislated protections.

2.9 Legislation

It is no surprise that rapid technological advancements in the fitness tracking arena outstrip the ability of legislators and data privacy advocates to implement legal protections for consumers' wearable data.⁴⁸ Lack of transparency regarding access to and use of gathered data by device manufacturers or third-parties is a significant problem.⁴⁹

In June 2019, Senators Amy Klobuchar (D-MN) and Lisa Murkowski (R-AK) introduced S.1842 Protecting Personal Health Data Act. This Act would require the Department of Health and Human Services (HHS) to promulgate rules and regulations "for technologies that collect personal health data, such as wearable fitness trackers [and] social-media sites focused on health data or conditions."⁵⁰

S.1842 incorporates concepts from the European Union General Data Protection Regulation (GDPR), including the user's right to access, delete, or change his or her health data, and would establish a national health task force to report to Congress for regulation purposes. As of this writing, the bill remains in committee.⁵¹

2.10 Third-Party Access to Data

Another security risk associated with data privacy in wearable health trackers is using third-party applications in conjunction with the data collected by a tracker. Sharing these data raises the potential for sharing personal information that was not explicitly disclosed. It is not uncommon for third-party applications to have more lax security measures for protecting their databases and data transfer. Understanding what data these extra applications collect and share, as well as what privacy settings they employ when in use, is paramount for the user. Lack of user knowledge and/or understanding about such sharing practices increases risk even when a user knowingly installs an app. Unless a user is thoroughly reading the Terms of Use, it is likely that decision is less than fully informed.

Orlosky, et al.⁵², published an evaluation of the accuracy and security of the Fitbit Blaze in 2019. The 24 participants revealed that most were willing to share their data for research purposes, but were less likely to be comfortable with data use by insurance companies, employers, or advertisers. Investigators examined third-party access to Fitbit user data and discovered that while Fitbit requires a third-party to submit a request to Fitbit and the user must grant access, the third-party is granted both read and write access to the data.⁵²

The results in this small survey likely stem from the sense that research data is anonymized, or, even if it is not, a subject's information is less likely to be used against them. Users may fear that health data gathered by trackers is inexact, yet may be used to discriminate against them by raising insurance premiums, denying professional advancement, or lead to other undesirable outcomes.

An evaluation in 2018 by Torre, et al., discovered that it may be possible for a third-party to infer personal undisclosed information about the device user. This ability to use raw data about one issue to make projections or draw conclusions about related issues, even if those are not explicitly disclosed or even measured, is troubling. Torre, et al., conclude that more transparent and standardized privacy permission notices would be beneficial when a third-party application is installed and given access.⁵³

2.11 Public by Default

Stricter privacy settings on devices often do exist, but they are frequently defaulted to being open and accessible. Thus, in order to keep information private, individual users must change default settings or toggle the setting on or off depending on circumstances. Many wearable apps offer the option to opt-out of sharing information, particularly with other compatible applications. This responsibility, too, falls on the user to change defaults and regularly check settings whenever terms and conditions change, as this may reset back to the original default.

This situation is referred to as “public by default” and is common across technology and applications which can be most useful when data can be aggregated or when seamless syncing of devices is a priority for users. Particularly in very insular communities, like Apple products, the ability to sync across products easily is a major selling point and one of the reasons that people will remain brand- (or platform) loyal. Companies also argue that access to user data and device use statistics assist them in developing even better products in the future.

Despite the benefits of this accessibility, “public by default” comes with some significant downsides when it comes to safety, security, and privacy. If a user is less technologically-inclined, they may not realize there are options to turn off or change default settings, or may not understand how to do so. Defaulting to “open” may compromise even savvy users, as they forget to recheck the defaults after a software update. New updates will frequently reset the defaults especially when the application's terms and conditions change. Passcodes, personal identification number (PIN) logins, biometric scans like

fingerprints, and other authentication methods are often utilized in mobile devices as extra levels of security, but are being slowly introduced into the wearable lifestyle tracker by researchers working to develop these strategies.⁴⁷

It is the user's responsibility to change default data-sharing and privacy settings and to remember to do this whenever terms and conditions change. Users are also encouraged to verify that third-party apps do not have "public by default" settings that might share their data, whether anonymized or not.⁵⁴

2.12 Health Information Protection

Perhaps one of the most concerning, or most pressing, issues of security or ethics is health-related data privacy protection.

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) protects a patient's rights to access their own health information, including granting permission to share this information. It is important to note that HIPAA protections only apply to "covered entities," which include health plans, most health care providers, health care clearinghouses, as well as business associates of covered entities. Unless an app developer is working with a covered entity, HIPAA protections would not apply. Independent app developers are not covered entities.⁵⁵

Protected health information, or individually identifiable health information, is health care-related information received or created by a covered entity that could reasonably be used to identify an individual.⁵⁶

HHS has provided use scenarios for app developers concerned about patient/user privacy and security⁵⁷ as well as guidance related to HIPAA and cloud computing.⁵⁸ However, unless a developer or cloud storage provider is a business associate of a covered entity, HIPAA privacy and security protections do not apply to the information gathered or stored by a tracking device or device manufacturer.

Two questions to ask of any fitness tracker are: what data are being collected and where are data being stored? The databases of personal health and wellness information are growing in size and popularity. Rapid advancements in the technology of fitness tracking are making protection of that data increasingly complex, with many companies basing their services and encrypted data in cloud-computing.⁴⁸ It seems likely that the next decade will see an increase in legislative wearable health data protection at the state and perhaps federal levels.

2.13 Liability of Healthcare Provider

As fitness and lifestyle trackers rise in popularity, their possible utility in general healthcare is being examined. Although there are still uncertainties related to accuracy and validity (see above), the devices could be useful for tracking trends in a patient. As device capabilities increase, the question of physician liability related to actions taken on the basis of wearable data may become more important.

Ahuja, et al., note that changes to medical practice will involve a discussion of physician liability, including establishing whether there exists a duty to engage in real-time data monitoring or accountability for the actions or outcomes of patients who are perhaps prescribed a tracking device.⁵⁹ It is likely that, in the absence of legislation, physician organizations like the American Medical Association will issue guidelines and lapses in these responsibilities will be resolved in the civil courts.

Health information gathered or stored at the behest of a HIPAA-covered entity will be governed by the privacy and security rules outlined there. Additional considerations for incorporation into medical records

are the necessity of valid data and, as the volume of data increases and uploads are automated, interoperability with the proprietary electronic health record software.

2.13.1. Unit Commander Dashboard/Fellow Airmen/Social Media

Manufacturers Garmin, Polar, and Suunto (devices not examined in-depth here) offer packages that allow integrated squad/team training, with dashboard access to statistics through a commander or coach level account. Most, if not all, devices allow data sharing with fellow users through the manufacturer's and other apps (e.g., Strava) or social media.

2.13.2. Validation/Gold Standard Testing/Verification

Despite their widespread use by all levels of fitness enthusiasts, the accuracy of wearable trackers has not been holistically validated. Tech review sites may compare heart rate monitor readings to strap-on chest monitors. Peer-reviewed, published literature is primarily focused on older, less expensive models. Fitness trackers are not considered medical devices and therefore are not required to be validated by the FDA.⁶⁰

The FDA's Center for Devices and Radiological Health (CDRH) defines "general wellness products" as those that "are intended for only general wellness use . . . and present a low risk to the safety of users and other persons." Product or service providers may not claim to diagnose or treat specific diseases or conditions except in a "general wellness claim." This type of statement can describe the intended use "as part of a healthy lifestyle" which may help to reduce the risk of or assist in living with certain chronic diseases or conditions.⁶¹

"[T]he FDA intends to apply its regulatory oversight to only those software functions that are medical devices and whose functionality could pose a risk to a patient's safety if the device were to not function as intended."⁶²

The FDA launched the Software as Medical Device (SaMD) Pre-Certification Pilot Program in 2017, which includes tracker manufacturers Apple, Fitbit, and Samsung as participants. This program will provide "streamlined and efficient regulatory oversight of software-based medical devices developed by manufacturers who have demonstrated a robust culture of quality and organizational excellence, and who are committed to monitoring real-world performance of their products once they reach the U.S. market."⁶⁴

Additionally, there are a handful of more recent investigations examining selected features on higher-end devices.

Two Garmin devices (Forerunner 920XT and Vivosmart HR) "did not show valid results concerning the estimation of VO_2 max and [energy expenditure]."⁶³ Other researchers compared the fēnix 5x to the gold-standard ParvoMedics TrueOne 2400 (PMT) VO_2 max measurement system and found that although the differences between the two were statistically significant, the fēnix 5 was an affordable alternative.⁶⁴ Swiss researchers evaluated energy expenditure measurement in the Polar Vantage M and found that accuracy decreased as activity requiring wrist and arm movements increased.⁶⁵

A sleep study comparing the Apple Watch sleep-tracking feature to the gold-standard Philips Actiwatch Spectrum Pro found that the Apple Watch had an overall accuracy of 97% and sensitivity of 99% in detecting actigraphy-defined sleep.⁶⁶ The Apple Watch has high step count accuracy when walking or jogging on a treadmill.⁶⁷ Chowdhury et al. deemed the Apple Watch to be the most accurate in measuring energy expenditure of four tested tracking devices, but still inferior to the two research-grade sensors. All of the consumer devices showed a tendency to overestimate energy expended.⁶⁸

2.13.2.1. Evidence for Behavior Modification

A systematic review of 463 research papers on wearable activity trackers published from 2013–2017 revealed that 83 (about 18%) described behavior change. However, most of the interventions described were relatively short in duration (less than 6 weeks). Although many researchers reported higher levels of physical activity among the intervention groups, it is not known how long these changes lasted or could be expected to last independently.⁶⁹

Brickwood et al. performed a systematic review to identify articles that included the use of a “consumer-based wearable activity tracker to improve physical activity participation” and sought to compare these interventions with those not using a tracker. They found that when comparing step count, moderate-to-vigorous physical activity, and energy expenditure, all of the intervention populations (using a tracker or not), performed better than the control groups.⁷⁰

Pitting individuals against members of social media peer groups may influence their intention to exercise, particularly if the “social sharing” and “social competing” remind the individual of their group’s norms and create a more positive attitude toward exercise.⁷¹

Although some research indicates that wearing a fitness tracker encourages more activity (research primarily looks at daily step count), another study comparing tracker-wearers to self-monitoring participants found few differences in physical activity between the two and the self-monitoring group lost more weight. A free-living study of office workers given the opportunity to purchase discounted Fitbits resulted in increased daily physical activity after 7 months. However, little is known about long-term behavior changes.⁷²

2.14 Future Devices and Capabilities

Wearable tracker use is widespread and seems unlikely to fade. New features and different technologies will continue to debut as sensor technology improves.

Transdermal therapeutic patches are already in use for a variety of needs, including smoking cessation, B12 deficiency, and motion sickness.⁷³ In 2017, the Taiwanese company E Ink announced a partnership with German LTS Lohmann Therapie-Systeme AG for the development of a Smart Patch for medication delivery that would “feature an E Ink display to deliver and convey relevant information about patch performance.”⁷⁴

An assessment released in 2016 by Edgewood Chemical Biological Center through the U.S. Army Research, Development, and Engineering Command (RDECOM) noted that in order to obtain information needed by the Chemical and Biological Defense Program, an “interoperable architecture” will need to be used in order to maximize the benefits from a wide array of sensors. The authors encourage work across the Department of Defense in order to “leverage expertise.” Finally, they recommend animal model verification of sensors, particularly those designed to identify chemical and biological agents.⁷⁵

A multi-level fusion framework based on Soldier-Body Sensor Networks has been described that would collect and compile data from other sensor nodes, allowing a soldier on the battlefield to make more informed decisions in real time as well as provide information to commanders behind the front lines.⁷⁶

Per Shin et al. (2019),⁶⁹ research so far has focused on the technology (“precision, reliability, accuracy and technological improvements”) and “the interaction of technology [and] its design ... with the user’s

needs, perceptions and expectations.” They identify a gap described as “the more existential interrelationship between people and their information needs.”

Santagati and Melodia (2017)⁷⁷ propose the use of ultrasonic communication as a novel networking framework for wearable devices. Their focus is primarily medical devices and they argue that, compared to radio frequency (RF)-based hardware, ultrasound is safer, more secure, offers better accuracy, and is easily reconfigurable.

3.0 Methods, Assumptions, and Procedures

3.1 Literature Review to Inform ORAU’s Market Analysis

ORAU researchers conducted a literature review using the strategy described in the Research Plan (Appendix A) for identifying peer-reviewed research about wearable technology. Source Inclusion/Exclusion Criteria were developed and used to select relevant peer-reviewed research (Appendix B).

Peer-reviewed literature related to fitness trackers fell into four broad categories: validation research, technology research, health interventions, and psychological investigations. Validation research was often device-specific and much of what was found featured older, less expensive models with limited capabilities. This is likely in part due to the time interval between experiment completion, article submission, and eventual publication. Technology research was primarily concerned with device security. Investigators often presented novel encryption methods to keep data private as it traveled via Bluetooth between wearables and other devices. Health interventions often targeted special populations, like the elderly or cancer survivors, to get an idea of how wearables could enhance general health or recovery. Studies that considered psychological investigations looked at the effects (if any) of free-living populations using fitness trackers.

Although ORAU found a substantial amount of available literature pertaining to the general state of wearable technology, literature was limited on specific device models. Therefore, it was necessary to search outside of the research literature to identify and analyze the strengths of currently available devices. Our team searched the open Web to find the state of currently available devices, described in this report as the “Market Analysis” contained in the Results and Discussion section. The current Methods, Assumptions, and Procedures section describes the ORAU team’s methodology for identifying and analyzing the features of currently available devices during fall 2019/early winter 2020 and reveals a new tool for comparing the top devices found through our research endeavor.

3.2 Project Scope

Because weight restrictions on equipment for Air Force personnel are an important factor when incorporating new technology, the ORAU team focused on researching primary devices (i.e., smartwatches) that would be able to perform heart rate monitoring (HRM) and pulse oximetry without substantial weight added. Thus, glasses and other secondary or tertiary devices were not considered feasible for Air Force personnel to wear because of weight restrictions. Further, limited peer-reviewed research was unavailable on effective combinations of primary and secondary devices (e.g., a specific smartwatch model paired with an external pulse oximeter). Therefore, ORAU's research efforts focused on identifying the top smartwatches currently available on the market.

3.3 Method and Process of Market Analysis

The ORAU team consisted of two sub-teams including the literature review team and the market analysis team. The two teams worked together (full team) throughout the duration of the project. ORAU followed a systematic process outlined below in integrating findings from the literature review with the market analysis. The team incorporated a peer review process throughout research and analysis activities.

- The literature review team reviewed literature on wearable technology and identified a gap in literature about the current models.
- The literature review team identified websites containing consumer reviews and expert reviews on wearable devices currently available on the market. The market analysis team identified two review sites that contain online comparison tools from Versus.com and DCRainmaker.^{78,79}
- The full team identified device inclusion criteria specifying which smartwatches would be included in a first sweep of the analysis. Device inclusion criteria were:
 - Reputable/quality brand (i.e., not for fashion purposes)
 - Security considerations (not including Chinese brands; including brands that have tested well for security)⁸⁰
 - The most advanced models (i.e., most features, most advanced metrics and sensors)
 - Commercially available
 - Brands where there is literature on past models
 - Price
- Based on findings from the literature review about specific device brands and models, the market analysis team collected data about 16 smartwatches from the two online comparison tools, merged data into one spreadsheet (Devices Matrix – now called Master Data on the tab of the spreadsheet), and cleaned data. The factors described by these review sites about device features were designated "criteria." (Appendix C contains a list of the top 16 smartwatches).
- The team further reduced the number of smartwatches to six based on device inclusion criteria listed above. Device models include the following:
 - Apple Watch Series 5
 - Garmin fēnix 6
 - Garmin Forerunner 945
 - Polar Vantage V
 - Samsung Galaxy Watch Active2
 - Fitbit Versa 2
- The market analysis team contacted the ORAU Cyber Security team to provide input on important security considerations for identifying devices. The security team identified a list of questions (Appendix D – Cyber Security Issues). The market analysis team used some of these questions as criteria for data security in the Devices Matrix spreadsheet and populated data points for those criteria.
- Two team members assigned relevant category labels (features and features subcategories) for all criteria statements.
- Two team members assigned importance levels to criteria in terms of their relevance to the Air Force and if they were considered important for differentiating key differences between smartwatches. Criteria were assigned the following labels: important, moderately important, least important, and don't know importance. Items labeled don't know importance were designated as such because it was unclear if certain features thought to be beneficial from a technological

standpoint could pose risks (i.e., security) or it was unclear if Air Force personnel would train in certain environments (i.e., swimming).

- The literature review team edited and confirmed agreement of the rankings of importance.
- The full list (>200) of criteria were reduced in stages to the most important 20 criteria, or differentiating criteria. A criterion may have been designated important (e.g., having an accelerometer), but if all of the top six devices met that criterion, it wasn't considered useful for differentiating between devices. The criteria considered important and moderately important were re-reviewed and assigned as differentiation criteria if there were a mix of yes and no entries across the six devices. To that end, a column for differentiating criteria was added to the matrix to show if criteria were considered differentiating (yes) or not (no), or designated not assessed if their level of importance was not important or don't know importance.
- Team members populated missing data from the review sites for the most important and moderately important criteria that were considered differentiating.
- The market analysis team removed criteria that duplicated data or included many missing data points for features considered not important.
- The full team reviewed the list of differentiating criteria and confirmed agreement of the process and results.
- The market analysis team identified areas where there were missing data for three devices that could be filled by data from previous models of those devices (e.g., missing data for Apple Watch Series 5 was populated with data from the same review site for Apple Watch Series 4 and notated "S4" preceding the data element. This was done similarly for Fitbit Versa 2 with Fitbit Versa ["FV"] and Samsung Galaxy Watch Active2 with Samsung Galaxy Watch Active ["SGA"]).
- Team members gathered and analyzed consumer reviews from Amazon.com to populate missing data in the Devices Matrix spreadsheet. (Appendix E)
- The market analysis team transformed the Devices Matrix into the Compare Smartwatches Tool. The team reviewed the design of the tool and facilitated user experience testing with two professionals not associated with the project to assess their understanding of the tool and instructions. The tool was revised to incorporate feedback from the testers.

Additional notes about coding data in the tool:

- "No data" was listed in cases where we searched for criteria ranked "important" or "moderately important" yet could not find the information to provide a yes or no response.
- "Mentioned" was added for security-related criteria if brands addressed a criterion in their security/privacy documentation.
- "N/A" labels were included if data were sought but could not be found.
- "Not assessed" refers to data points where the expert/consumer review sites have not yet provided that information for certain models. The team agreed to limit our research to filling in those data gaps for only criteria considered differentiating.

3.4 Compare Smartwatches Tool

ORAU's research approach included compiling and organizing the available data about the top smartwatches on the consumer market in an Excel spreadsheet called the Device Matrix. Instead of recommending a specific device for all use cases, our research led us to propose the use of a tool that

helps differentiate between key features that would be important for a particular use case (e.g., human performance, deployment to a harsh climate). Therefore, the Device Matrix was transformed into a tool so that it can be used to support the various use cases identified by the Air Force. The tool can be used to filter and search features found in the top smartwatches. We have provided some pre-filtered views (Quick Views) in separate tabs for Human Performance and for Design and Technical Specs. The following section includes instructions for a user (“you”) on how to use the tool and a “How to Use the Tool” worksheet is available within the tool.

3.4.1. Welcome Screen Worksheet

The welcome screen links you to the worksheet housing the tool where you can compare the features of the top smartwatches assessed in ORAU’s research. You can link to the spreadsheet where you can update data. It also includes tips for using the tool. Click on the Compare Smartwatches box to get started using the tool.

3.4.2. Compare Smartwatches Tool Worksheet

The tool on this worksheet includes three sections:

- The top section is the results dashboard that updates based on the selections you choose from the section below it.
- The middle section includes blue filter boxes where you can click on different options to filter devices by various criteria. You can also use a search box to search feature subcategories or to search the criteria. Look for the red text and arrows that say Search.
- The bottom section populates information about six different smartwatches based on the blue filters that are selected or what was selected from using the search boxes.

There are over 200 criteria that were evaluated by consumer review and expert review websites, and also ORAU staff. The criteria are categorized according to various features including fitness tracking and health tracking, and then further subcategorized in the second filter box. Criteria were also categorized according to their importance, and if they are useful in showing key differences between models, which we are calling differentiating criteria.

3.4.3 Master Data (or “Devices Matrix”) Worksheet

The third tab called “Master Data” includes information that populates the Compare Smartwatches Tool in the second tab. This is where the Device Matrix can be edited. The edited data will repopulate in the tool automatically after clicking Data from the top menu and then Refresh All.

3.4.4 Quick View Worksheets (Example: “QV. Human Performance”)

These pre-filtered views are designed to show the relevant criteria for particular use cases. They can be modified using the filter boxes.

4.0 Results and Discussion: Market Analysis

ORAU conducted a market analysis of six smartwatch models from Garmin, Polar, Apple, Fitbit, and Samsung. The analysis included a comparison of the smartwatch models according to cost; operating system and compatibility; software/apps; connectivity; data sharing; data collection and analysis; data storage; battery life; algorithms and machine learning; location; durability; wearability; design; training required; and extra features.

4.1 Cost

Smartwatches are priced according to their materials/size and features related to connectivity and sensors. The base price listed below accounts for the model with the least advanced options (Table 1). The Garmin fēnix 6 series includes 12 different models that have different sizes, extras, Wi-Fi capabilities, a sapphire crystal glass on the display, and solar charging capabilities. Higher-priced Apple Watches can come with additional connectivity options including cellular and cellular + GPS. The price of smartwatches listed here does not include the cost of paired phones. For instance, the best performance of the Apple Watch requires it to be paired to an iPhone. For the Polar Vantage V, the base price does not include a heart rate sensor.

Table 1. Cost

	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Cost	\$599.99	\$599.99	\$499.95 and up (without heart rate sensor)	\$269.99	\$399.00 and up	\$149.95

4.2 Operating System and Compatibility

Smartwatches contain a mobile operating system that includes capabilities of data connection and, in some cases, mobile communication. Five of the top six reviewed smartwatches are compatible with Android and iOS mobile devices, and Apple Watch Series 5 is only compatible with iOS. In addition, some watches are compatible with Windows Phone, Mac OS, and Windows. The following includes compatibility of the top six smartwatches with Android, iOS, and other technology:

Garmin fēnix/Forerunner 945 are compatible with iOS and Android through the Garmin Connect app. (Some Garmin devices are having connectivity issues with iOS 13, the link in the comment provides instructions on solving the issue).⁸¹

- Garmin fēnix/Forerunner 945 are Windows Phone compatible and compatible with Mac OS and Windows through Garmin Express.^{82,83}

Apple Watch Series 5 is not Android compatible.

Polar Vantage V is compatible with iOS and Android through the Polar Flow app. (Minimum requirements include: iOS mobile devices with iOS 11 and later; Android mobile devices with Bluetooth 4.0 and Android 5 or later).⁸⁴

- Polar Vantage V is not Windows phone compatible.⁷⁹

Fitbit Versa 2 is compatible with most devices with the following OS: iOS 11 or higher; Android 7.0 and higher.⁸⁵

- Fitbit Versa 2 is compatible with Windows 10 v1607 or higher.⁸⁵

Samsung Galaxy Watch Active2 is compatible with iOS and Android through the Galaxy Wearable app; iPhone5 or later with iOS 9 and above are compatible; Android 5.0 and RAM of 1.5 gigabytes (GB) or higher are supported.⁸⁶

4.3 Software/Apps

Software is available as open source, for purchase, or proprietary (specific to the device brand). Software such as apps, widgets, and watch faces can be downloaded through digital distribution services such as [Google Play](#), [Connect IQ](#) (Garmin), and [Apple App Store](#) (Table 2).⁸⁷⁻⁸⁹ Apps include digital maps, personal organizers, and schedulers. Widgets are described as “previews of your favorite apps” that can display data (e.g., weather) without opening an app. Watch faces provide a customized look to the smartwatch.

Table 2. Software⁸⁷⁻⁸⁹

Software Options By Device	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Open-Source	Connect IQ*	Connect IQ	Google Play Store ***	Google Play Store	Apple App Store	App Gallery**
Purchase	Connect IQ	Connect IQ			Apple App Store	**
Proprietary	Connect IQ	Connect IQ		Galaxy Store		**

* Includes data field, device apps, watch faces, widgets

** Fitbit has an App Gallery, but it requires an account <https://dev.fitbit.com/> | <https://gam.fitbit.com/>

*** Watch faces

4.4 Wireless Connectivity

Technical/engineering standards include short-range wireless communication protocols such as Bluetooth and Adaptive Network Topology (ANT), which allow devices to communicate in wireless networks. All six devices use Bluetooth technology (meet the Bluetooth SIG Standards) and Garmin devices additionally use ANT+ for wireless communication between devices and fitness sensors (such as used by fitness equipment) (Table 3). Further, these six devices use Bluetooth Smart, also known as Bluetooth Low Energy or Bluetooth LE. Bluetooth Smart provides better communications in terms of range and coverage while using less power.⁹⁰ ANT+ enables monitoring devices to talk to each other; ANT+ products allow for interoperability across different brands.⁹¹

Table 3. Wireless Connectivity^{78,79}

	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Bluetooth Version	4.2	4.2	4.2	5.0	5.0	4.0
Bluetooth Smart	Yes	Yes	Yes	Yes	Yes	Yes
ANT+	Yes	Yes	No	No	No	No

4.5 Device Connectivity, Apps, and Data Sharing

The smartwatch is used in conjunction with other devices, tools, and apps to exchange data that can inform the user. A device's functionality can be enhanced with the use of apps, provided that the hardware and sensor technology is advanced enough and compatible with the app. Each device is connected to a service that delivers compatible apps. Due to the large universe of apps in the marketplace, our research focus was to identify the top smartwatches for various use cases. We have provided some examples about apps, but have not listed specific recommendations for apps.

Third-party apps are compatible with the smartwatch if obtained through the device's respective digital distribution service as shown in Table 2 above. Apps can monitor any of the following: sleep, stress, substance abuse, nutritional intake, activity monitoring, health coaching, behavioral intervention strategies, and lifestyle exposure monitoring. Apps include online services that allow the user to track exercise/diet through use with the smartwatch, a smartphone, and a Web app (e.g., MyFitnessPal, which tracks calories by logging activities and tracking data about foods reported).

Below is an example that describes connectivity between a smartwatch and the cloud, between a smartwatch and its app, between a smartwatch and a third-party app, and data sharing between Web services. Data from the watch is transferred to the cloud. This occurs when the smartwatch communicates with the accompanying cloud service (e.g., Garmin Connect) by uploading data (e.g., through Bluetooth) to an app on the user's phone (or computer). The cloud service then exchanges data with a third-party app or Web service.

For example, the user wears his Garmin watch on a run. When his run is finished, he stops and saves the activity on the watch. When he gets near his phone, data from the running activity is uploaded to the Garmin Connect App. The Garmin Connect account is paired with his MyFitnessPal App account and his calories burned during the activity are shared with MyFitnessPal. MyFitnessPal uses data from his run to readjust the readout of the remaining calories for the day based on goals he has set through his MyFitnessPal account. Similarly, data from a smart scale (an enhanced bathroom scale that connects wirelessly to a smartwatch to provide weight and body composition data) can be gathered, tracked, and shared with compatible apps to help the user with weight management/fitness goals.

The following includes compatibility of the top six smartwatches with related third-party apps:

- Garmin fēnix/Forerunner 945
 - Third-party watch apps are available through Connect IQ Store.
 - Garmin devices are compatible with apps such as Lose It, MyFitnessPal, Runkeeper through the Garmin Connect app – see partnered apps, most third-party apps will only receive data from Garmin Connect, only MyFitnessPal, Strava, Training Peaks, and Zwift can send data.
 - Activity reports can be exported as .csv files from Garmin Connect online.
 - Garmin Index Smart Scale will pair with the Garmin Connect app.
- Apple Watch Series 5
 - Some third-party health apps such as Lose It are compatible through Apple Health integration.
 - MapMyRun, Endomondo and MyFitnessPal are available for the Apple Watch through the App Store.⁹²
 - Smart scale: Withings Body+ Body Composition Wi-Fi Scale

- Polar Vantage V
 - Polar devices are compatible with MyFitnessPal through Polar Flow app and online portal – see all compatible apps.
 - Compatible with some third-party power sensors
- Fitbit Versa 2
 - The Fitbit App Gallery provides apps and watch faces for the Versa 2. Free, proprietary, and third-party apps are available.
- Samsung Galaxy Watch Active2
 - Apps for the Samsung Galaxy Watch Active2 can be obtained from the Galaxy Store or Google Play.

Appendix F includes more details about third-party apps.

4.6 Device-To-Device Connectivity

Smartwatches can communicate with their companion devices (e.g., phone or computer) and external monitors incorporating a variety of sensor technology (e.g., heart rate monitors, fitness equipment, smart scales). An example of pairing smartwatches with external monitors occurs for HRM (Table 4). Two of the six devices are compatible with third-party heart monitors. Garmin and Polar both manufacturer HRMs that pair with their own devices. Samsung, Apple, and Fitbit do not currently make their own HRMs. External HRMs can include chest straps or arm bands. The chest HRM uses electrical impulses to measure heart rate whereas the arm band uses an optical sensor. These sensors transfer heart rate data by Bluetooth Smart or ANT+. ⁹³ Most arm-band HRMs have rechargeable batteries while chest straps do not. ⁹⁴

Table 4. Compatibility of heart rate monitors^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Compatible with heart rate straps made by same brand	Yes	Yes	Yes	No	No	No
Compatible with third-party heart rate monitors	No	Yes	No	No	Yes	No

4.7 Cloud Computing

Cloud computing involves “the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer.” ⁹⁵ All six smartwatches are capable of wirelessly syncing with a phone through a phone app, and the upload process occurs through Bluetooth. The data are transferred from the smartwatches to cloud computing services.

4.8 Data Collection/Analysis

The following includes examples of data collection and reporting that manufacturers provide in their user manuals about real-time and continuous data management.

4.8.1. Real-time

Real-time data collection and reporting is commonly used for these models for assessing performance during a workout:

- Garmin fēnix 6 provides real-time feedback about the user's performance condition during an activity and how close the user is to achieving their training target, such as a distance or speed goal.
- Garmin Forerunner 945 provides real-time training target, running form feedback, performance condition (approximately the real-time percentage deviation from baseline VO₂ max estimate). Live Event Sharing provides real-time event updates to followers.
- Samsung Galaxy Watch Active2 can be used with an app called MapMyRun that provides real-time workout feedback.
- Polar Vantage V does not mention real-time functionality in its manual. However, this smartwatch can use Race Pace to get real-time feedback about the user's pace during the run. Also, the watch can be used with Strava Live Segments, which provides real-time data on how the user's performance compares to others. (Strava's default privacy settings display the routes of users on their heat map, which has been noted as an operational security risk for revealing military bases and positions. Strava has announced that military users opt out of the heat map, and the Pentagon has restricted troops from using devices with geolocation at sensitive locations).^{40,96}
- Apple Watch Series 5 allows the user to manually take an ECG to monitor heart rate and the waveform is displayed in real-time. Notifications about high, low, and irregular heart rates can be sent when noticed. The noise app can be used to display real-time data about ambient noise.
- Fitbit Versa 2 provides real-time heart rate and resting heart rate that pair with Exercise app to provide real-time statistics.

4.8.2. Continuous

Continuous data collection is used for measuring heart rate and blood oxygen saturation during sleep. Although the key benefit of continuous data collection is extensive amounts of data, it also means reduced time deploying a device to allow the battery to be recharged.⁹⁷ The following include examples of continuous data collection for the top six smartwatches:

- Samsung Galaxy Watch Active2 can be configured to monitor and track heart rate and stress continuously, every 10 minutes, or manually.
- Garmin fēnix 6 has options to continuously measure blood oxygen saturation during sleep. The device continuously collects elevation and pressure data.
- Apple Watch content is continuously backed up to its paired iPhone.
- Fitbit Versa 2 continuously tracks statistics when worn.
- Garmin Forerunner 945 continuously measures blood oxygen saturation during sleep, and continuously collects elevation and pressure data.
- Polar Vantage V continuously measures heart rates.

4.9 Internet-Connected Trackers

All six smartwatches are capable of syncing wirelessly and four automatically sync data when the smartwatch is in range with the user's phone or computer.

- Garmin fēnix 6 and Forerunner 945 user manuals do not mention automatic syncing.
- Polar Vantage V watch syncs with the Polar Flow app automatically after a training session if the phone is within the Bluetooth range.
- Apple Watch Series 5 syncs automatically.
- Samsung mentions an auto-sync function for audio and image files.
- Fitbit has an all-day sync feature which can be enabled.

4.10 Data Storage

The amount of data storage is an important consideration especially for situations when smartwatches are deployed and are not connected to the Internet. Manufacturers report the memory capacity of smartwatches in terms of its central processing unit (CPU), memory, and storage (Table 5).

- Garmin fēnix 6 can store 64 megabytes (MB) of memory/history.⁹⁸
- Garmin Forerunner 945 can store 200 hours of activity data. Data storage includes the following metrics: distance, time, pace, calories, average heart rate (HR), max HR, training effect (TE), cadence, vertical oscillation, vertical ratio, ground contact time (GCT), GCT balance, stride length, lap, map, time in zones. Vertical oscillation, vertical ratio, GCT, GCT balance, and stride length require a paired HRM.⁹⁹
- Fitbit Versa 2 appears to require all-day sync to be enabled for best results, which may mean that offline storage is not optimal. Activity and sleep data are viewed through the Fitbit app.¹⁰⁰
- Apple Watch has 32 GB of internal storage.
- Polar Vantage V: data on internal/offline storage capability were not found.
- Samsung Galaxy Watch Active2 has 4 GB of internal storage.

Table 5. Memory/Storage

Device	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
CPU	Not available	Not available	Not available	Dual core 1.15 GHz	64-bit dual-core S5 processor	Not available
Memory	64 MB	4.5 GB (~6.6 GB is usable); 200 hours of activity data	Up to 90 hours of training with GPS and heart rate depending on language settings	RAM 1.5 GB Long-Term Evolution (LTE), 0.75 GB non-LTE	32 GB (internal, no card slot)	Saves 7 days of detailed motion data, minute by minute Saves daily totals for past 30 days
Storage	Internal storage 64 MB	4.5 GB (~6.6 GB is usable)	Not available	4 GB	Capacity 32 GB (GPS + Cellular or GPS)	64 Internal storage - About 4 GB

4.11 Algorithms and Machine Learning

The proprietary technology of smartwatches and companion devices, apps, and the cloud use algorithms and machine learning to help a user “recognize what [she] is currently doing, while at the same time offering information or an experience that is pertinent to that specific contextual situation.”¹⁰¹

All of the top smartwatches collect data from sensors (e.g., motion, heart rate) and communicate through their accompanying apps to bring data back to the user in a way that provides insight through metrics. Examples include:

- Movement sensors detect deep sleep, light sleep, and an awake state can help the user learn about their sleep patterns last night and recently.
- Step detector, step counter, and accelerometer sensors are used to recognize and count steps (and the pace), and data are rolled up so that the user can compare today’s steps against daily averages.
- Sensors can detect when a user falls down and if there is movement soon afterwards. If no movement is detected, the Apple Watch calls emergency services.¹⁰²
- A pulse oximetry sensor in the Garmin watches helps gauge the peripheral saturation of oxygen in blood. Oxygen saturation is useful in determining how the body is acclimating to high altitudes. Garmin smartwatches show the most recent pulse oximetry reading and previous readings from the past 24 hours juxtaposed on a graph of elevation readings from the past 24 hours. (The Polar Vantage V, Apple Watch Series 5, Samsung Galaxy Watch Active2, and Fitbit Versa 2 do not have a pulse oximeter sensor).^{79,103}
- A heart rate monitor can be used to estimate fitness using an estimated VO_2 max metric.

Below is an example of how algorithms use heart rate data to calculate and analyze fitness performance and provide actionable insight.

Resting heart rate data can be a predictor of heart health.¹⁰⁴ Heart rate data collected during exercise can be used to identify training zones (i.e., target heart rates related to exercise intensity) which can then be incorporated in training sessions. Web apps allow users to set up a training plan based on heart rate zones. Users create workout goals with these apps and upload the workout parameters to their smartwatch. The device will sound an alert when the heart rate is outside of the specified training zone based on an algorithm estimating VO_2 max by the smartwatch.^{105,106} (For information on accuracy, refer to this study by the University of Delaware: “[How accurate is your Garmin’s \$\text{VO}_2\$ max estimate?](#)”)¹⁰⁷ This feedback from the smartwatch alerts the user of their heart rate so they can take the desired action (e.g., change pace).

4.11.1. Population Trends

Social fitness networks such as Strava Segments Live can be used to compare one’s running or cycling performance to other individuals who ran or cycled on the same segments of a road or trail. As previously noted, because routes data from individual users is displayed on Strava’s heat map and could be an operational security risk for sensitive operations, Strava has suggested military users opt out of using the heat map functionality.

4.12 Battery Life

All of the top devices have a rechargeable battery with an indicator that shows the user when the device has a low battery level (Table 6). Because GPS functionality requires additional battery power, devices are listed by battery life overall and the battery life with the GPS on. Garmin and Polar devices reported the longest battery life with and without GPS activated.

Table 6. Battery Life^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Battery life	14 days	14 days	7 days	2.5 days	0.75 days	6 days
Battery life with GPS on	36 hours	36 hours	40 hours	24 hours	< 0.75 days	n/a
Has wireless charging	No	No	Yes	Yes	Yes	No

4.13 Location (GPS)

GPS is a U.S.-owned global navigation system that enables global positioning, which is a useful function for using maps and navigation. All of the devices except for Fitbit Versa 2 have GPS. Garmin Forerunner 945 “acquires GPS faster” by periodically downloading data on the future position of GPS satellites.⁷⁹ For security reasons, it could be important to be able to disable GPS services. Garmin watches allow the ability to turn GPS off/on. Our research did not reveal whether or not it was possible to disable GPS on the other top devices. All six smartwatches allow users to record their routes taken through the GPS recording functionality (Fitbit requires use of a paired phone). The five smartwatches that use GPS are also compatible with additional global navigation satellite systems, including Galileo, GLONASS, and QZSS, which are owned by Europe, Russia, and Japan, respectively. A-GPS, Assisted Global Positioning System, uses a mobile network. The Garmin devices use turnaround points, or waypoints, to aid navigation. Additional GPS/navigation specifications are included in Table 7 below:

Table 7. Location/GPS^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Follow GPS track (courses/waypoints)	Yes	Yes	No	SGA: no	S4: With 3rd party apps	FV: no
GPS specifics	GPS/ GLONASS/ Galileo	GPS/ GLONASS/ Galileo	GPS/ GLONASS	GPS/ GLONASS/ A-GPS	A-GPS/ GLONASS/ GALILEO/ QZSS	No, uses phone GPS
Routable/visual maps (like car GPS)	Yes (Pro Only)	Yes	No	SGA: no	S4: With 3rd party apps	FV: no

4.14 Durability

All of the top devices are dustproof, waterproof, and sweat-resistant (Table 8). Several smartwatches have a waterproof depth rating of 100 meters, while others only 50 meters. The highest operating temperature among these was reported to be 60 Celsius (°C) while the lowest potential operating temperature is specified at -20 °C.

Most of the devices (but not Apple Watch Series 5) have a damage-resistant glass that can withstand high levels of force. Half of the devices (Garmin Forerunner 945, Samsung Galaxy Watch Active2, Fitbit Versa 2) use Corning Gorilla glass for this purpose.

Garmin has an external ANT+ wireless temperature sensor to measure ambient air. This sensor can be paired with the fēnix 6 and Forerunner 945. The Garmin devices also have an internal sensor. The body's temperature affects the internal sensor and should be removed from the wrist for 20–30 minutes to get an accurate reading.¹⁰⁸

Table 8. Durability^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Has branded damage-resistant glass	Yes	Yes	Yes	Yes	No	Yes
Lowest potential operating temperature	-20 °C	-20 °C	-10 °C	0 °C	0 °C	-10 °C
Maximum operating temperature	45 °C	45 °C	50 °C	40 °C	35 °C	60 °C
Temp recording (external sensor)	Yes	Yes	No	SGA: no	S4: no	FV: no
Temp recording (internal sensor)	Yes	Yes	Yes	SGA: yes	S4: no	FV: no
Waterproof depth rating	100 meters	50 meters	100 meters	50 meters	S4: 50 meters	50 meters

4.15 Wearability

ORAU selected smartwatches because of their ability to perform HRM and pulse oximetry while taking up a small size/weight to meet Air Force parameters of limited weight.

One of the tradeoffs for selecting a small, light smartwatch is having a small screen size, which can affect user experience. The two lightest watches of this group were Samsung Galaxy Watch Active2 and Apple Watch. The three smartwatches with the best ratio of screen size to weight were Garmin Forerunner 945, Apple Watch Series 5, and Samsung Galaxy Watch Active2.

Table 9 includes device specifications.

Table 9. Device Specifications^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Height	47 mm	47 mm	46 mm	44 mm	44 mm	40 mm
Screen size	1.3 in.	2 in.	2 in.	1.4 in.	1.78 in.	1.34 in.
Thickness	14.7 mm	13.7 mm	13 mm	SGA: 10.5 mm	10.74 mm	not assessed
Volume	32.47 cm ³	30.26 cm ³	27.51 cm ³	SGA: 16.38 cm ³	17.96 cm ³	not assessed
Weight	80 g	50 g	66 g	30 g	36.7 g	38 g
Width	47 mm	47 mm	46 mm	44 mm	38 mm	40 mm
Screen Size Per Weight Ratio	0.016	0.040	0.030	0.047	0.049	0.035

in. = inch

cm³ = cubic centimeters

mm = millimeters

4.16 Design

The design of the top smartwatches influences user experience. The devices shown have an electronic display that is backlit and clearly viewed. Some additional factors to consider include if the device (Table 10):

- Has a display that is always on and can show the date, time, and notifications (all but Garmin fēnix)
- Has a touch screen (Garmins do not), including Force Touch/3D Touch, which responds to the user's taps depending on the force on the input
- Has voice commands, allowing use of the smartwatch without pushing any buttons
- Has a display that has good image quality, especially organic light-emitting diode (OLED) or active-matrix organic light-emitting diode (AMOLED) displays
- Shows advertisements, which can be distracting

The consumer review website, Versus.com, scores devices overall.⁷⁸ Of the top six smartwatches from our research, the two smartwatches with the highest rankings were Garmin Forerunner 945 and Samsung Galaxy Watch Active2.

Table 10. Design and user experience^{78,79}

Criteria	Garmin fēnix 6 series	Garmin Forerunner 945	Polar Vantage V	Samsung Galaxy Watch Active2	Apple Watch Series 5	Fitbit Versa 2
Ad-free	No	Yes	No	Yes	Yes	No
Always-on Display	No	Yes	Yes	Yes	Yes	Yes
Has a touch screen	No	No	Yes	Yes	Yes	Yes
Has an OLED or AMOLED display	No	Not assessed	No	Yes	Yes	Yes
Has Force Touch/3D Touch	No	No	No	No	Yes	No
Has voice commands	No	No	No	Yes	Yes	Yes
Pixel density	283 ppi	283 ppi	283 ppi	SGA: 463 ppi	326 ppi	Not assessed
Resolution	260 x 260 px	240 x 240 px	240 x 240 px	SGA: 360 x 360 px	368 x 448 px	300 x 300
Versus points score	88	100	73	100	98	74

4.17 Training Required

All researched brands have user manuals available online.^{24,100,108-111} In addition, some of the brands provide online tutorials through videos, including hosting YouTube channels and personal online sessions (Apple) (Table 11). Further, expert review websites such as DCRainmaker provide videos about smartwatches that are available on YouTube.com.

Table 11. Training Resources

Smartwatch	Description	Website URL
Garmin	YouTube channel with How To, Tips and Tricks, Get Started, and How to Set Up videos	https://www.youtube.com/user/garminblog/channels
Apple Watch Series 5	Apple Watch offers online personal sessions	https://www.apple.com/shop/browse/personal_session
Polar Vantage V	YouTube channel with How To, Tips and Tricks, Get Started, and How to Set Up videos	https://www.youtube.com/user/PolarUSA
Fitbit Versa 2	How To videos	https://www.fitbit.com/us/how-to-videos
Samsung Galaxy Watch Active2	Smartwatch Solutions and Smart Simulator	https://www.samsung.com/us/support/mobile/wearables/smartwatches http://samsungsimulator.com/

These videos include how to operate the smartwatch and view reports/data visualization. For Garmin devices, Garmin Connect provides Help files linked from some of the reports screens. If documentation on outputs is not included in the user manuals or help videos, it will be important to use the smartwatch and develop customizable training materials.

Terms used in training materials are often consistent within the same brand, but not necessarily across brands. If the Air Force decides to use multiple smartwatch brands and models, it will be important to develop a customized training manual and user guide that includes terminology consistent across different devices.

4.18 Extras

Because our research focus was to identify the top devices for human performance and training, we included information on extras in the Compare Smartwatches Tool, yet did not focus our efforts evaluating additional features that may be nice to have but not necessary. Additional features include the following:^{78,79}

- Alarm – silent (vibrating) alarm or a smart alarm that wakes up the user when in a light state of sleep
- Alerts/notifications – alerts include vibrating, visual, and audio
- Cellular connection – Apple Watch with cellular allows users to make a call, send a text, and stream music without using the phone
- Compass – includes 3-D compass
- Specific activities – including diving, golf, hunting, fishing, parachuting
- Music – music storage and playback including the ability to access streaming services and pair Bluetooth headphones
- Payments – ability to make payments that use near-field communication (NFC) technology to exchange data between watch and readers such as through Apple Pay and Android Pay eWallets or EMV chip cards
- Phone – can be used to answer calls, phone notifications of texts and calls can be sent to watch, phone locator
- Photos
- Social features – integrates with social networks
- Stopwatch/timer

5.0 Conclusion

In conclusion, lifestyle, fitness, and activity tracking devices have a large and growing applicability across a wide variety of fields, from medical to insurance to research, and can be used as appropriate for every level of user, from fitness amateurs to professional athletes to other health and exercise enthusiasts. As the sophistication of such wearable technology grows—including watches, rings, clothing, glasses, and more—the number and complexity of measurements and features they possess only increases as well, adding to their usefulness. By being capable of tracking everything from exercise and sports to biological vital signs to environmental exposure, their overall utility is high.

While there are some limitations with the devices in terms of data transfer, security, harsh or hazardous environments, separate electronic ecosystems, and third-party applications that lack interoperability, wearable lifestyle tracking shows feasibility as an accurate research and training tool to pursue.

For fitness tracking, the most useful and capable devices are smartwatches, which were more feasible for wear in environments where weight and bulkiness are not a concern. These smartwatches ranged from the mass-produced Apple Watch to more technical varieties and brands like Garmin and Polar. In order to evaluate these devices, ORAU performed a literature and research review of information and data pertaining to wearable technology and then conducted a market analysis of available devices in a spreadsheet matrix. By identifying and analyzing the various features present in devices, we observed over 200 criteria that were narrowed to twenty important and differentiating criteria—from security concerns to specific measurement capabilities. This helped us to narrow the field down to the top six models, and we constructed a new matrix tool (Compare Smartwatches Tool) to compare the best devices. This included two Garmin devices, the Apple Watch, and one each from Polar, Samsung, and Fitbit.

While any of these six smartwatches are very capable, there are subtle differences that could impact usability, depending on the use environment and the specific measurements required. The Compare Smartwatches Tool can be used to filter and search through features in the smartwatches, whether through a few pre-filtered views related to human performance or technical specifications, or personal customizations.

Ultimately, the dynamics of wearable usage are highly dependent on the individual wearing it, their psychology and motivations, and their lifestyle. Aspects of privacy, usefulness, accuracy, and motivation all play into the behavior decisions of users and, in the long run, the effectiveness of such technological tools.

6.0 Recommendations

Our research demonstrated that a smartwatch is currently the best type of device for fitness tracking and health purposes. Despite this, our research indicated that it was not feasible to make recommendations for a particular smartwatch without knowing the specific circumstances under which users of various job fields and requirements would operate those devices. Therefore, the devices we propose in the Compare Smartwatches Tool are our top choices of brands and models, and we recommend using the tool to identify criteria that are appropriate for the intended use case.

The tool is designed to encompass scalability for personnel at different levels. Various criteria for important device features for each level of personnel could be identified and the tool could be used to show the best fit for those criteria. A future version of the tool could include a mechanism for selecting the most relevant criteria for different levels of personnel, and/or a pre-filtered view could be designed for scalability.

Once a device is selected for a particular use case, a next step for additional research would involve identifying compatible apps for a particular device that is deemed effective by expert/consumer reviews and possibly user testing.

Given the rapid pace of technological change, it is not feasible to make a recommendation for a specific smartwatch at a particular time. In the process of finalizing this report (January 23, 2020), Garmin announced a new watch designed for military use.¹¹² Our comparison tool indicates two current Garmin models as useful for a variety of relevant applications, and our research team has plans to follow up and learn more about the new Garmin model when that information becomes available. The new Garmin model could be added to the Compare Smartwatches Tool for further comparison.

7.0 References

1. WageWorks. Wearable technology may be subject to HIPAA. 2019; <https://www.wageworks.com/employers/employer-resources/compliance-briefing-center/legislation-and-reform/legislation-insights/2019/wearable-technology-may-be-subject-to-hipaa/>. Accessed Jan 8, 2020.
2. Freeman-Mills M. Wearable spending expected to soar to \$52 billion in 2020. 2019; <https://www.wareable.com/wearable-tech/wearables-spending-20-billion-2020-report-gartner-7738>. Accessed Jan 22, 2020.
3. WT | Wearable Technologies. 37TH WT | Wearable Technologies conference 2020 USA. 2019; <https://www.wearable-technologies-us.com/>. Accessed Jan 22, 2020.
4. United States Food and Drug Administration. Digital health software precertification (pre-cert) program. 2019; <https://www.fda.gov/medical-devices/digital-health/digital-health-software-precertification-pre-cert-program>. Accessed Jan 22, 2020.
5. Freeman-Mills M. Fitbit goes big on helping to detect the early signs of atrial fibrillation. 2019; <https://www.wareable.com/fitbit/fitbit-atrial-fibrillation-afib-study-pfizer-heart-7703>. Accessed Jan 22, 2020.
6. Apple. Taking an ECG with the ECG app on Apple Watch Series 4 or later. 2019; <https://support.apple.com/en-us/HT208955>. Accessed Jan 22, 2020.
7. Langley H. Fighting the silent killer: Blood pressure is wearable tech's next challenge. 2018. <https://www.wareable.com/health-and-wellbeing/wearable-blood-pressure-tech-559>. Accessed Jan 8, 2020.
8. Sawh M. Pulse oximeter: why SpO2 and blood oxygen will be huge in 2020. 2020; <https://www.wareable.com/wearable-tech/pulse-oximeter-explained-fitbit-garmin-wearables-340>. Accessed Jan 22, 2020.
9. FIFA. About the IMS standard for wearable tracking devices. nd; <https://football-technology.fifa.com/en/media-tiles/about-the-ims-standard-for-wearable-tracking-devices/>. Accessed Jan 6, 2020.
10. NFL Players Association. WHOOP strikes landmark deal as the officially licensed recovery wearable of the NFL Players Association. 2017; <https://www.nflpa.com/players/news/whoop-strikes-landmark-deal-as-the-officially-licensed-recovery-wearable-of-the-nfl-players-association>. Accessed Jan 10, 2020.
11. Mischke J. Wearable technology: the latest trend in professional sports. 2018; <https://www.wearable-technologies.com/2018/05/wearable-technology-the-latest-trend-in-professional-sports/>. Accessed Jan 22, 2020.
12. Chen A. What happens when life insurance companies track fitness data? 2018. Accessed Jan 10, 2020.
13. O'Neill S. As insurers offer discounts for fitness trackers, wearers should step with caution. 2018; <https://www.npr.org/sections/health-shots/2018/11/19/668266197/as-insurers-offer-discounts-for-fitness-trackers-wearers-should-step-with-cautio>. Accessed Jan 22, 2020.
14. Raber I, McCarthy CP, Yeh RW. Health insurance and mobile health devices: opportunities and concerns. *JAMA - Journal of the American Medical Association*. 2019;321(18):1767-1768.
15. Motiv. Motiv Ring. 2020; <https://mymotiv.com>. Accessed Jan 10, 2020.
16. Oura. Oura ring. 2020; <https://ouraring.com>. Accessed Jan 11, 2020.
17. blinq. blinq. 2019; <https://blinqblinq.com>. Accessed Jan 22, 2020.
18. Bellabeat. Bellabeat. 2019; <https://www.bellabeat.com/>. Accessed Jan 22, 2020.
19. Bellabeat. App-solutely everything about the Bellabeat app! *b*. Vol 2019: Belbeat; 2018.

20. Moov. Moov. 2020; <https://welcome.moov.cc/>. Accessed Jan 10, 2020.
21. WHOOP. WHOOP. 2019; <https://www.whoop.com/>. Accessed Jan 22, 2020.
22. Sawh M. The best smart clothing: From biometric shirts to contactless payment jackets. 2018; <https://www.wearable.com/smart-clothing/best-smart-clothing>. Accessed Jan 22, 2020.
23. Solos. Solos smart glasses. 2019; <https://solos-wearables.com/>. Accessed Jan 22, 2020.
24. Apple. Apple Watch Series 5. 2019; <https://www.apple.com/apple-watch-series-5/health/>. Accessed Jan 22, 2020.
25. Sumra H. Our health-based wearable future will be dominated by ecosystems. 2017; <https://www.wearable.com/wearable-tech/health-wearable-future-ecosystem-lock-in-249>. Accessed Jan 22, 2020.
26. Wright SP, Hall Brown TS, Collier SR, Sandberg K. How consumer physical activity monitors could transform human physiology research. *American Journal of Physiology - Regulatory Integrative and Comparative Physiology*. 2017;312(3):R358-R367.
27. Friedl KE. Military applications of soldier physiological monitoring. *Journal of Science and Medicine in Sport*. 2018;21(11):1147-1153.
28. Hill S. Who's tracking your fitness tracker? we asked an expert. 2016; <https://www.digitaltrends.com/wearables/whos-tracking-your-fitness-tracker/>. Accessed Jan 13, 2020.
29. Aledhari M, Marhoon A, Hamad A, Saeed F. A new cryptography algorithm to protect cloud-based healthcare services. 2017.
30. Aksu H, Uluagac AS, Bentley ES. Identification of wearable devices with Bluetooth. *ArXiv*. 2018;abs/1809.10387
31. PCMag. Geotracking. *PC Magazine's online encyclopedia* 2019.
32. Redenius N, Kim Y, Byun W. Concurrent validity of the Fitbit for assessing sedentary behavior and moderate-to-vigorous physical activity. *BMC Medical Research Methodology*. 2019;19(1).
33. Montes J, Tandy R, Young J, Lee S-P, Navalta J. A comparison of multiple wearable technology devices heart rate and step count measurements during free motion and treadmill based measurements. *International Journal of Kinesiology and Sports Science*. 2019;7(2):10.
34. Siddall AG, Powell SD, Needham-Beck SC, et al. Validity of energy expenditure estimation methods during 10 days of military training. *Scandinavian Journal of Medicine and Science in Sports*. 2019;29(9):1313-1321.
35. Fitbit. Fitbit Health & Activity Index™. 2020; <https://www.fitbit.com/us/activity-index>. Accessed Jan 23, 2020.
36. Centers for Disease Control and Prevention. Behavioral Risk Factor Surveillance System. 2020; <https://www.cdc.gov/brfss/>. Accessed Jan 20, 2020.
37. Evenson KR, Wen F, Furberg RD. Assessing validity of the Fitbit indicators for U.S. public health surveillance. *American Journal of Preventive Medicine*. 2017;53(6):931-932.
38. Naval Health Research Center. *Wearable Activity Tracker Literature Review (January 2009 – July 2016)*. San Diego, CA 2017.
39. Burbach L, Lidynia, C., Brauner, P., & Ziefle, M. Data protectors, benefit maximizers, or facts enthusiasts: identifying user profiles for life-logging technologies. *Computers in Human Behavior*. 2019;99:9-21.
40. Hern A. Fitness tracking app Strava gives away location of secret US army bases 2018; <https://www.theguardian.com/world/2018/jan/28/fitness-tracking-app-gives-away-location-of-secret-us-army-bases>. Accessed Jan 20, 2020.
41. Lyons EJ, Swartz MC. Motivational dynamics of wearable activity monitors. *ACSM's Health and Fitness Journal*. 2017;21(5):21-26.
42. Hsu J. The Strava heat map and the end of secrets. *Wired: Security*. 2018. <https://www.wired.com/story/strava-heat-map-military-bases-fitness-trackers-privacy/>.

43. Sly L, D. L, Timberg C. U.S. military reviewing its rules after fitness trackers exposed sensitive data. *The Washington Post* 2018.
44. Copp T. Fitbits and fitness-tracking devices banned for deployed troops. 2018; <https://www.militarytimes.com/news/your-military/2018/08/06/devices-and-apps-that-rely-on-geolocation-restricted-for-deployed-troops/>. Accessed Jan 8, 2020.
45. Lotfy K, Hale ML. Assessing pairing and data exchange mechanism security in the wearable internet of things. 2016.
46. Tahir H, Tahir R, McDonald-Maier K. On the security of consumer wearable devices in the Internet of Things. *PLoS ONE*. 2018;13(4).
47. Park YS, Yu SB, Yoon H, Kim HS, Seo J, Chung JM. Force sensor activated authentication for wearable devices. *Information (Japan)*. 2017;20(6):4163-4169.
48. Fietkiewicz KJ, & Henkel, M. . Privacy protecting fitness trackers: an oxymoron or soon to be reality. International Conference on Social Computing and Social Media; 2018; Las Vegas, NV.
49. Spann S. Wearable fitness devices: personal health data privacy in Washington state. *Seattle University Law Review*. 2016;39(4).
50. Tonsager L, A.D. K, Ackerman W, Ponder J. Legislation seeks to regulate privacy and security of wearables and genetic testing kits. *Inside Privacy* 2019; <https://www.insideprivacy.com/data-privacy/legislation-seeks-to-regulate-privacy-and-security-of-wearables-and-genetic-testing-kits/>. Accessed Jan 22, 2020.
51. Klobuchar A. S. 1842 - Protecting Personal Health Act. GovTrack.us: Civic Impulse LLC; 2019.
52. Orlosky J, Ezenwoye O, Yates H, Besenyi G. A look at the security and privacy of Fitbit as a health activity tracker. Paper presented at: 2019 ACM Southeast Conference 2019; Kennesaw, GA.
53. Torre I, Sanchez OR, Koceva F, Adorni G. Supporting users to take informed decisions on privacy settings of personal devices. *Personal and Ubiquitous Computing*. 2018;22(2):345-364.
54. Miller M. Strava lesson: share fitness data online? check these privacy settings now. 2018; <https://www.zdnet.com/article/share-fitness-data-online-check-these-privacy-settings-now/>. Accessed Jan 22, 2020.
55. United States Department of Health and Human Services. Health information privacy. nd; <https://www.hhs.gov/hipaa/index.html>. Accessed Jan 22, 2020.
56. Health Insurance Portability and Accountability Act of 1996, 42 USC 1171(6) United States Code(1996).
57. United States Department of Health and Human Services. Health app use scenarios & HIPAA. 2016; <https://hipaaqportal.hhs.gov/community-library/accounts/92/925889/Public/OCR-health-app-developer-scenarios-2-2016.pdf>. Accessed Jan 22, 2020.
58. United States Department of Health and Human Services. Guidance on HIPAA & cloud computing. 2017; <https://www.hhs.gov/hipaa/for-professionals/special-topics/cloud-computing/index.html>. Accessed Jan 22, 2020.
59. Ahuja N, Ozdalga E, Aaronson A. Integrating mobile fitness trackers into the practice of medicine. *Am J Lifestyle Med*. 2016;11(1):77-79.
60. Advisory Board. FDA will not regulate fitness tracker apps, other healthy lifestyle software. 2019; <https://www.advisory.com/daily-briefing/2019/09/30/fda-guidance>. Accessed Jan 22, 2020.
61. United States Food and Drug Administration. General wellness: policy for low risk devices guidance for industry and Food and Drug Administration staff. 2019; <https://www.fda.gov/media/90652/download>. Accessed Jan 22, 2020.
62. United States Food and Drug Administration. Policy for device software functions and mobile medical applications: guidance for industry and Food and Drug Administration staff. 2019; <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/policy-device-software-functions-and-mobile-medical-applications>. Accessed Jan 22, 2020.

63. Passler S, Bohrer J, Blöchinger L, Senner V. Validity of wrist-worn activity trackers for estimating VO2max and energy expenditure. *International Journal of Environmental Research and Public Health*. 2019;16(17).
64. Anderson JC, Chisenall T, Tolbert B, Ruffner J, Whitehead PN, Connors RT. Validating the commercially available Garmin Fenix 5x wrist-worn optical sensor for aerobic capacity. *International Journal for Innovation Education and Research*. 2019;7(1):147-158.
65. Gilgen-Ammann R, Schweizer T, Wyss T. Accuracy of the multisensory wristwatch Polar Vantage's estimation of energy expenditure in various activities: instrument validation study. *Journal of Medical Internet Research*. 2019;21(10).
66. Roomkham S, Hittle M, Cheung J, Lovell D, Mignot E, Perrin D. Sleep monitoring with the Apple Watch: comparison to a clinically validated actigraph [version 1; peer review: 2 approved with reservations, 1 not approved]. *F1000 Research*. 2019;8.
67. Veerabhadrapa P, Moran MD, Renninger MD, Rhudy MB, Dreisbach SB, Gift KM. Tracking steps on Apple Watch at different walking speeds. *Journal of General Internal Medicine*. 2018;33(6):795-796.
68. Chowdhury EA, Western MJ, Nightingale TE, Peacock OJ, Thompson D. Assessment of laboratory and daily energy expenditure estimates from consumer multisensor physical activity monitors. *PLoS ONE*. 2017;12(2).
69. Shin G, Jarrahi MH, Fei Y, et al. Wearable activity trackers, accuracy, adoption, acceptance and health impact: a systematic literature review. *Journal of Biomedical Informatics*. 2019;93.
70. Brickwood KJ, Watson G, O'Brien J, Williams AD. Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. *Journal of Medical Internet Research*. 2019;21(4).
71. Zhu Y, Dailey SL, Kreitzberg D, Bernhardt J. "Social networkout": connecting social features of wearable fitness trackers with physical exercise. *Journal of Health Communication*. 2017;22(12):974-980.
72. Sullivan AN, Lachman ME. Behavior change with fitness technology in sedentary adults: A review of the evidence for increasing physical activity. *Frontiers in Public Health*. 2017;4(JAN).
73. Williams A. How Qualcomm and E Ink's smart patches could shake up health monitoring. 2017; <https://www.wearable.com/health-and-wellbeing/smart-patches-biometrics-qualcomm-life-e-ink-765>. Accessed Jan 22, 2020.
74. E Ink and LTS partner develop smart patch to improve medical management [press release]. 2017.
75. Hirschberg DL, Samuels AC, Rosenzweig CN, et al. Assessment of wearable technology for integrated decision support. 2016.
76. Shi H, Zhao H, Liu Y, Gao W, Dou SC. Systematic analysis of a military wearable device based on a multi-level fusion framework: research directions. *Sensors (Switzerland)*. 2019;19(12).
77. Santagati GE, Melodia T. U-wear: software-defined ultrasonic networking for wearable devices. 2015.
78. Versus. Search: smartwatch. 2019; <https://versus.com/en/search?q=smartwatch>. Accessed Jan 20, 2020.
79. DC Rainmaker. Product comparison calculator. 2020; <https://www.dcrainmaker.com/product-comparison-calculator>. Accessed Jan 20, 2020.
80. AV Test. Fitness trackers – 13 wearables in a security test. 2018; <https://www.av-test.org/en/news/fitness-trackers-13-wearables-in-a-security-test/>. Accessed Jan 20, 2020.
81. Garmin. Support center. 2020; <https://support.garmin.com/en-US/?faq=oMQAW20SpY06UD0itn27o7>. Accessed Jan 22, 2020.
82. Garmin. Register, update software & sync your device. 2020; <https://www.garmin.com/en-US/software/express>. Accessed Jan 20, 2020.
83. DC Rainmaker. Garmin Forerunner 945 multisport watch in-depth review. 2019. Accessed Jan 20, 2020.

84. Polar. Support. 2020; https://support.polar.com/en/support/polar_flow_app_and_compatible_devices, 2020 Jan 22.
85. Fitbit. Let's get down to specifics. 2020; <https://www.fitbit.com/us/technology/compatible-devices>. Accessed Jan 20, 2020.
86. Samsung. Samsung smart watch and phone compatibility. 2020; <https://www.samsung.com/us/support/answer/ANS00082502/>. Accessed Jan 20, 2020.
87. Google. Google Play: Apps. 2020; <https://play.google.com/store/apps>. Accessed Jan 20, 2020.
88. Garmin. Connect IQ store. 2020; <https://apps.garmin.com/en-US/>. Accessed Jan 20, 2020.
89. Apple. App Store. 2020; <https://www.apple.com/ios/app-store/>. Accessed Jan 20, 2020.
90. Vesternet. What is Bluetooth smart 2020; <https://www.vesternet.com/pages/what-is-bluetooth-smart>. Accessed Jan 20, 2020.
91. ANT+. Your health & fitness partner. 2020; <https://www.thisisant.com/consumer/ant-101/what-is-ant>. Accessed Jan 20, 2020.
92. MyFitnessPal. Introducing MyFitnessPal for the Apple Watch! 2020; <https://blog.myfitnesspal.com/introducing-myfitnesspal-for-the-apple-watch/>. Accessed Jan 20, 2020.
93. DC Rainmaker. Wahoo TICKR FIT optical HR sensor in-depth review. 2018; <https://www.dcrainmaker.com/2018/01/wahoo-tickr-fit-optical-hr-sensor-in-depth-review.html>. Accessed Jan 20, 2020.
94. Duffy J. The best heart rate monitors for 2020. 2020; <https://www.pcmag.com/picks/the-best-heart-rate-monitors>. Accessed Jan 20, 2020.
95. Dillon-Roberts S. An overview of cloud computing. 2018; <http://digitalresources.nz/article/OZcgU6Y>. Accessed Jan 20, 2020.
96. Military Times. Fitbits and fitness-tracking devices banned for deployed troops. 2018; <https://www.militarytimes.com/news/your-military/2018/08/06/devices-and-apps-that-rely-on-geolocation-restricted-for-deployed-troops/>. Accessed Jan 20, 2020.
97. Godfrey A, Hetherington V, Shum H, Bonato P, Lovell NH, Stuart S. From A to Z: wearable technology explained. *Maturitas*. 2018;113:40-47.
98. Garmin. Garmin Fenix 6: specs. 2020; <https://buy.garmin.com/en-US/US/p/641449#specs>. Accessed Jan 20, 2020.
99. Garmin. Forerunner 945: specs. 2020; <https://buy.garmin.com/en-US/US/p/621922#specs>. Accessed Jan 20, 2020.
100. Fitbit. Fitbit Versa 2: user manual version 1.2. 2020; https://staticcs.fitbit.com/content/assets/help/manuals/manual_versa_2_en_US.pdf. Accessed Jan 20, 2020.
101. WT | Wearable Technologies. Is it time for the smartwatches to start listening carefully? 2018; <https://www.wearable-technologies.com/2018/05/is-it-time-for-the-smartwatches-to-start-listening-carefully/>. Accessed Jan 20, 2020.
102. Apple. Use fall detection with Apple Watch. 2020; <https://support.apple.com/en-us/HT208944>. Accessed Jan 20, 2020.
103. Garmin. Pulse ox acclimation on your Garmin watch 2018; <https://www.youtube.com/watch?v=Qi0SNvB2mU4>. Accessed Jan 20, 2020.
104. Solan M. Your resting heart rate can reflect your current — and future — health. *Harvard Health Blog*. Vol 2020. Harvard Health Blog; Harvard Health Publishing, Harvard Medical School; 2016.
105. Garmin. Using Garmin Connect training plans 2020; <https://support.garmin.com/en-US/?faq=o21H5a4cSU52FwFAy0R6Z5>. Accessed Jan 20, 2020.
106. Polar. Running program. 2020; <https://www.polar.com/us-en/smart-coaching/running-program>. Accessed Jan 20, 2020.

107. University of Delaware. How accurate is your Garmin's VO₂ max estimate? 2019; <https://sites.udel.edu/coe-engex/2019/03/16/how-accurate-is-your-garmins-vo2max-estimate/>. Accessed Jan 20, 2020.
108. Garmin. Fenix 6: owner's manual. 2019; http://static.garmin.com/pumac/fenix_6_6S_6X_Pro_OM_EN-US.pdf. Accessed Jan 20, 2020.
109. Garmin. Forerunner 945: owner's manual. nd; <https://www8.garmin.com/manuals/webhelp/forerunner945/EN-US/GUID-B8165803-CB4B-4348-B0D8-190DDDD8080C-homepage.html>. Accessed Jan 20, 2020.
110. Samsung. Samsung Galaxy Watch Active 2. 2020; http://downloadcenter.samsung.com/content/PM/201910/20191016062616910/EB/WEA_R82X_R83X_EN_FINAL_190918/start_here.html. Accessed Jan 20, 2020.
111. Polar. Polar Vantage V user manual. nd; https://support.polar.com/e_manuals/vantage-v/polar-vantage-v-user-manual-english/content/introduction.htm. Accessed Jan 20, 2020.
112. WT | Wearable Technologies. Garmin Announces Tactix Delta, a Multisport GPS Smartwatch Built to Military Standards. 2020; <https://www.wearable-technologies.com/2020/01/garmin-announces-tactix-delta-a-multisport-gps-smartwatch-built-to-military-standards/>. Accessed Jan 23, 2020.

List of Acronyms, Abbreviations, and Symbols

°C	Celsius
%	percent
AMOLED	active-matrix organic light-emitting diode (display)
AR	augmented reality
BMI	body mass index
BRFSS	Behavioral Risk Factor Surveillance System
CDC	Centers for Disease Control and Prevention
CDRH	Center for Devices and Radiological Health
CPU	Central processing unit
DLW	doubly-labelled water
ECG	electrocardiogram
EPTS	electronic performance and tracking system
FDA	Food and Drug Administration
FIFA	Fédération Internationale de Football Association
GB	gigabytes
GCT	ground contact time
GDPR	European Union General Data Protection Regulation
GPS	Global Positioning System
HHS	Department of Health and Human Services
HIPAA	Health Insurance Portability and Accountability Act of 1996
HR	heart rate
HRM	heart rate monitoring
ICMetric	Integrated Circuit Metric
IEEE	Institute of Electrical and Electronics Engineers
JAG	Judge Advocate General
JAMA	Journal of the American Medical Association
LTE	Long-Term Evolution (network)
MB	megabytes
NFC	near-field communication
NFL	National Football League
NFLPA	National Football League Players Association
NPR	National Public Radio
OLED	Organic light-emitting diode (display)
ORAU	Oak Ridge Associated Universities
OS	operating system
PMT	ParvoMedics TrueOne 2400
QV	quick view
RDECOM	Research, Development, and Engineering Command
RF	radio frequency
SaMD	Software as Medical Device
TE	training effect
USAF	United States Air Force
UV	ultraviolet
VO ₂ max	maximal oxygen uptake

Appendix A – Research Plan

Background

To identify appropriate publications and other resources, ORAU will determine initial keywords appropriate to the identification and evaluation of lifestyle tracking devices. Key databases to be searched include Web of Science, Scopus, and PubMed (from the National Center for Biotechnology Information, or NCBI). Search engine Google will be used to identify manufacturer websites, reviews, and other gray literature.

Keywords, synonyms, and subject headings will be compiled in an initial list and modified based on in-search results. Example keywords include but are not limited to: lifestyle track*, fitness track*, health track*, activity track*, wearable, smartwatch*, electronic performance and tracking systems (EPTS). Brand and model names (e.g., Garmin fēnix, Fitbit Versa) will be used as these are identified and evaluated.

Search strategies will include the use of Boolean operators, wildcards, truncation, proximity searching, and limitation options. PubMed articles are tagged with information about their structure as well as their content and major topics in the article. Web of Science, however, has structure information tags but does not have content tags.

Database searches will be limited from 2015 to present. Only current models of lifestyle trackers will be examined. Information regarding forthcoming models will be provided if available.

Appendix B – Source Inclusion/Exclusion Criteria

Preliminary evaluation of source based on currency, relevance, authority, accuracy, and purpose

Inclusion Criteria

Source must be available in English

Source should be no older than July 2016

If device-specific:

- No medical interventions/clinical populations
- Device must be commercially available
- Device must be current model/not discontinued
- Not a smartphone app
- Not a research-grade device/medical testing device

Device type

Primary

Watches

Secondary

- Wrist or arm band
- Glasses
- Rings
- Clothing, including inserts or attachments
- Watch + other wearable

Tertiary

Future tech, e.g., tattoos, subdermal implants

Evaluate

Publication Type

- Peer reviewed
- Conference Proceedings
- Industry publication
 - Use for technical specs
- Consumer review
 - Expertise level/sophistication
 - How long has site existed/person been reviewer
 - For less authoritative reviews, i.e., device purchasers, quantity/general trends seen
 - In positive/negative reviews

Research organization or funding source

- Devices provided by manufacturer
- Devices purchased by lab, reviewer, etc.

Appendix C – List of Top 16 Smartwatches
Apple Watch Series 3

Apple Watch Series 4
Apple Watch Series 5
Fitbit Ionic
Fitbit Versa
Fitbit Versa 2
Garmin fēnix 6 series
Garmin fēnix 6S Pro
Garmin fēnix 6X series
Garmin Forerunner 935
Garmin Forerunner 945
Polar Ignite
Polar Vantage M
Polar Vantage V
Samsung Galaxy Watch
Samsung Galaxy Watch Active2

Appendix D – Cyber Security Issues

Cyber security issues for wearable devices used by military:

- Information Security
- Operational Security
- User Privacy
- Cloud (includes data storage and transmission)

Questions to consider:

- Is the location of the individual sensitive?
- How is data transferred to the app/website?
- Is GPS tracking in use?
- If yes to GPS enabled, can it be disabled?
- If GPS is disabled, does it degrade the effectiveness of the tracker (cannot do location, so it does not know how far you have walked/run/biked)?
- How are data securely transmitted (e.g., for cloud storage)? How are data stored? Are data shared?
- For applications used/allowed, what do they collect, share, and how/where their data are stored?
- Are there privacy settings that go along with the app? (View and configure)
- Are there data sharing settings that are included in the app for social media? (View and configure)
- What is the ability to manage/baseline devices for a secure configuration (to address issues above)?

Appendix E – Differentiating Criteria and Amazon Reviews

Eleven criteria were selected as differentiating, meaning that these features were deemed important enough to influence recommendation of a product for a particular purpose. The criteria are listed in table format in the Compare Smartwatches Tool, setting filter Differentiating Criteria to yes.

Criteria include: Automatically syncs; Battery life; Battery life with GPS on; Compatible with third-party heart rate monitors; Device upload; Encryption and firewall technology used for personal data collection and storage; Has passcode; Monitors blood oxygenation levels (pulse oximetry); Profile privacy; Storage & processing; and VO₂ max estimation.

Amazon reviews marked Verified and Helpful for each of the top seven devices were examined to see if and how many reviews mentioned the identified differentiating criteria and what was the tone or context of the review. The top six devices are: Apple Watch 5, Fitbit Versa 2, Garmin fēnix 6 series, Garmin Forerunner 945, Polar Vantage V, and Samsung Galaxy Watch Active2. A total of 348 verified and helpful reviews were identified.

Apple Watch 5 (42 reviews)

Poor battery life was mentioned by two of the seven 1-star reviews. Poor battery life was noted in one of the two 2-star reviews. A 3-star review noted that the watch software restricts its use to the region in which it was purchased, making use of a U.S.-purchased watch outside of North America difficult or impossible. Two of the four 4-star reviews mentioned poor battery life as a disappointment. Three of the 26 5-star reviews noted poor battery life. None of the other identified themes appeared in the selected reviews.

Fitbit Versa 2 (95 reviews)

In the 36 1-star reviews, none directly addressed any of the differentiating criteria. Most of the 1- and 2-star reviewers were dissatisfied with the Fitbit software and its (in)ability to connect with the reviewer's phone or tablet. Of the 11 2-star reviews, one reviewer noted that the "VO₂ sensor" did not provide data but seemed to be referring to pulse oximetry rather than VO₂ max estimation. Two 2-star reviews noted that the battery life for the style of watch was very good.

Eight 3-star reviews included critiques of the software and some features of the phone (vibration, sleep tracking); one review noted that the battery needed to be charged nightly, among other issues. The 4-star reviews tended to be lengthier than the lower stars and three made positive comments related to battery life. However, disappointments related to setup, software, and syncing to phone were noted even in these reviews.

Twelve of the 30 5-star reviews mentioned battery life as a positive attribute or deciding factor in their purchase. Even the 5-star reviewers noted that setup or software syncing was an issue at some point although they were more tolerant of this (perhaps more tech-savvy?). Reviewers mentioned sleep tracking as a key feature, although some were disappointed that advanced sleep statistics were only available through a Premium Fitbit subscription.

Garmin fēnix 6 series (includes Garmin fēnix 6S Pro) (38 reviews)

Seven 1-star reviews identified a variety of disappointments, including an easily scratched face, inconsistent heart rate sensor and GPS, software issues, and display problems or perceived inadequacies.

In the five 2-star reviews, purchasers identified the HRM sensor as inconsistent and noted that the watch often had trouble with Bluetooth connections (phone and earbuds). One reviewer was disappointed in the lack of crisp contrast on the display and another felt the battery life was inadequate.

Five 3-star reviews varied in their level of detail and concern, but one notable theme was the inaccuracy of the heart rate monitor when compared to a heart rate strap or other smartphone. One reviewer specifically described the heart rate inaccuracy when performing high intensity interval training, but noted that for steady-state activity like running or biking, it was accurate. Another reviewer stated that the solar power feature did not charge the watch, merely slowed the battery drain. Three of these reviews noted the mapping feature was well done and fairly accurate.

There were only three 4-star reviews. One was critical specifically regarding the inability to play Audible audiobooks in native format. The other two reviews noted that battery life was good and that the variety of sensors (heart rate, pulse oximeter, and VO₂ max) performed as expected.

Of the 16 5-star reviews, 6 praised battery life, even when using GPS and/or pulse oximetry features. The accuracy of the heart rate sensor compared to other heart rate monitors was mentioned by five reviewers.

Garmin Forerunner 945 (39 reviews)

The nine 1-star reviewers stated that their experience with the device's GPS was poor (2); encountered difficulty with syncing, updating, or connectivity generally (3); felt the battery life was not as advertised (2); or that the heart rate sensor was inaccurate (2).

Five 2-star reviews identified issues with the poor display (lack of contrast or bright colors), poor battery life, inaccuracy of the heart rate monitor, and connectivity problems.

The two 3-star and two 4-star reviews were unrelated to the differentiating criteria. One review criticized the device's build quality ("mushy" buttons) and two other reviews seemed to be rating the seller or listing rather than the device itself.

In the 21 5-star reviews, battery life, with and without GPS or pulse oximetry use, was mentioned favorably in 10 reviews. Two reviewers identified the GPS service as a positive and two reviews felt favorably about the connection to other devices such as foot pods or heart rate monitors. Several reviewers applauded the sleep tracking and "body battery" (recovery monitoring) data.

Polar Vantage V (38 reviews)

Three of the five 1-star reviews identified connectivity/syncing problems and another referred to "bad software." The fifth reviewer was disappointed in the accuracy of heart rate readings during activities other than walking or jogging. The three 2-star reviews were in a similar vein: one reviewer, who was familiar with earlier Polar products, felt the software was unfinished. The other two reviews focused on the inaccuracy of the heart rate monitor and one of these also mentioned that the software seemed to have bugs.

Three of the four 3-star reviews were written by individuals who identified as previous users of Polar's V800 models. Two felt that the heart rate and GPS compared unfavorably to the earlier model. Another regretted the decision to upgrade, citing a dim display, small fonts, and the lack of training data displayed when the activity is paused. The fourth reviewer was also dissatisfied with the display although acknowledged that battery life was good.

The five 4-star reviews contained similar criticisms as the lower ratings, but, notably, one reviewer mentioned the heart rate accuracy of the device compared favorably to a heart rate strap. Two reviewers stated that the GPS was very accurate while another disagreed. One reviewer shared that the screen got scratched the first day of wearing the device.

Twenty-one reviewers gave 5-star rankings, citing accurate heart rate measurement (8), good battery life (6), good GPS accuracy (2), good screen legibility (5), and useful recovery recommendations (7).

Samsung Galaxy Watch Active2 (59 reviews)

Three of the six 1-star reviews referred to a cosmetically damaged or opened product purchased as New. Two reviewers experienced difficulty syncing the device with their phone and the last did not provide useful details.

The eight 2-stars reviews covered many topics, some of them quite user-specific (although arguably useful). For example, the heart rate sensor was unable to detect heart rate through tattoos, tennis is not included in the preset fitness activities, and a user was unable to sync the watch with his Office 365 Calendar. Other reviewers experienced very short battery life (1), inaccurate sensor readings (3), or were simply “utterly disappointed” in its banality for the price (1).

Out of six 3-star reviews, one reviewer praised battery life and HRM, but noted that the GPS was inaccurate and step counts were low. Another reviewer praised the smartwatch features of the device but felt that the fitness tracking functions fell short. A third reviewer felt that battery life was too short and had to charge their device daily.

Eight purchasers gave 4-star reviews. Four of these noted that the device was primarily a smartwatch with fitness tracking features, but they would not consider it a fitness tracker. Two reviewers felt the battery life was not as long as advertised.

Thirty-one purchasers felt the watch merited a 5-star review. It was very clear that different reviewers had very different expectations for battery life with reviews noting the following: poor battery life (5), good battery life (9), and battery life as expected (2).

One reviewer shared that the HRM numbers were comparable to a chest strap. Two reviewers purchased the device specifically for the ECG feature (when approved by the FDA). Most of the reviews focused on the smartwatch features of the device rather than fitness tracking.

Appendix F – Third-Party Apps

Table F-1. Third-Party Apps

Third-Party App		Website URL
MyFitnessPal	Tracks calories, breakdown ingredients	https://www.myfitnesspal.com/
Strava	Connects runners and cyclists	https://www.strava.com/
Training Peaks	Provides training plans and progress tracking tools	https://www.trainingpeaks.com/
Zwift	Provides a game-like setting to indoor training	https://zwift.com/
MapMyRun	A mobile run tracking app	https://www.mapmyrun.com/
Endomondo	A personal trainer app	https://www.endomondo.com/