

# Gamified Reality: Identifying the Psychological Attributes of Body Worn Sensors

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## ABSTRACT

Precision rehabilitation includes delivering the right practice, in the right dosage, to the right person, at the right time. This experience can have an engaging effect, immersing the user or mover. The downstream effects of precision rehabilitation are increasingly becoming more well-documented. Inherent in the name and concept, precision is not a uniform dosage that we can apply to all persons of a diagnostic group, sport, position, or skill level - it includes a person-specific recipe that will evolve as the user improves - and fatigues. Wearables may serve as an exceptional tool in our efforts to provide precision medicine, rehabilitation, and skill development in that these tools can capture real time data about performance, provide feedback, and combine these with the natural human response to being measured. In skilled rehabilitation and performance coaching we are yet to fully explore the psychological effects of being measured. A wearable can be an accelerometer, sensor, or body tracker that is recording your movements (or lack thereof), throughout your practice, game, work shift or day. Is the use of a wearable creating a healthy gamified reality, or an Orwellian-burden of being watched? As the landscape shifts in every field and through the continuum from skill development to performance to wellness and healthcare, it is time for us to consider the psychological effects of all forms of tracking devices (accelerometers, tracking devices, virtual reality and more) - on the learner. What are the ranges of gamified opportunities and the cautions regarding wearing any device that can measure and inform us, or inform someone else? How can we best personalize each opportunity in an effort to1 maximize the benefits?

### Key Terms

- 1) **Mechanism:** The underlying system or process that explains how something works.
  - 2) **Inform:** To provide information that helps someone understand or make decisions.
  - 3) **Influence:** The capacity to have an effect on the behavior or development of something.
  - 4) **Diagnostic:** Related to identifying problems or conditions, often used in medical or technical contexts.
  - 5) **Predictive:** Capable of forecasting future events or behaviors based on current data.
  - 6) **Evaluative:** Pertaining to assessing or judging the quality, importance, or effectiveness of something.
  - 7) **Raw Metrics:** Direct, unprocessed data collected during measurement, often without analysis.
  - 8) **Calculated Constructs:** Metrics or measures derived through processing or analysis of raw data.
  - 9) **Binary:** A system or process that has two possible states (e.g., true/false, yes/no).
  - 10) **Quantified:** Data that has been measured and expressed in numerical terms.
- Subjective Input Allowed: Allowing for personal opinions, judgments, or experiences in the data collection process.
- 11) **Laboratory:** A controlled, often artificial environment used for testing and research.

- 12) **Real World:** Refers to natural settings and conditions, outside of controlled environments like laboratories.
- 13) **General:** Broad, applicable to a wide range of cases or situations.
- 14) **Specific:** Focused on a particular detail or narrow aspect of a broader topic.
- 15) **All-day Wear:** Products or devices designed for continuous use over an entire day.
- 16) **Haptic:** Pertaining to touch or tactile feedback through vibrations or forces.
- 17) **Visual:** Pertaining to sight, involving images or displays that are seen by the user.
- 18) **Real-time:** Data or feedback provided immediately as events occur, with no delay.
- 19) **Delayed:** Data or feedback that occurs after a set period, not immediately after the event.
- 20) **Notifications:** Alerts or messages delivered to inform users about specific events or actions.
- 21) **On-screen/app Display:** Visual output presented on a screen or mobile app interface.
- Motion Capture: Technology used to record the movement of objects or people, often for analysis or animation.
- 22) **Macro:** Large-scale or overarching processes or measurements, often involving broad datasets.
- 23) **Biometric:** Pertaining to physiological or behavioral characteristics used for identification or measurement (e.g., heart rate, fingerprint).
- 24) **Sensor Placement Fixed:** A sensor that is positioned in a specific, unchanging location.
- 25) **Sensor Placement Moveable:** A sensor that can be adjusted or moved to different locations.
- 26) **Biochemical:** Relating to the chemical processes and substances that occur in living organisms.
- 27) **Biomechanical:** Pertaining to the mechanical aspects of biological systems, such as how muscles and bones work together.
- 28) **Bioelectrochemical:** Involving both biological systems and electrical/chemical processes, often used in applications like biosensors.

## Introduction

Patient (or athlete) engagement has clear relevance in skill development and in recovery. Recent developments in patient engagement have included technology such as virtual reality (VR) and wearables; has evolved to include concepts of behavioral economics (e.g. nudge, gamification) and have more recently evolved to include personalization (autonomy and preferences from the learner). When we have greater levels of engagement, we are likely to have elevated levels of intensity, attention and attendance (compliance) [1]. Not every method of engagement works for every person though. Some individuals need more success, some prefer a greater challenge. Some learners require and prefer more feedback and direction, others prefer more self-directed learning and feedback delivery on exceptions or after a repetition is complete. Clearly, the learning experience must be personalized. By enhancing engagement and personalization, we include the learner and optimize the learning, on our way toward precise care (precision). Virtual reality (VR) can offer an engaging environment via full immersion or semi-immersion. Learners can endure practice longer when they see themselves through an avatar representation on a screen moving through a virtual environment [2,3]. Takita and colleagues went so far as to rhetorically ask if we need human coaching/instructors anymore, with the advent of VR.3 Most every VR experience will include some sort of body-worn sensor (wearable) that in-

dicates movement choices or performance on the part of the learner.

This can include something as simple as goggles or a headset driving the visual scan of a virtual environment or more complex in the case of a glove, ankle bracelet or full accelerometer system, which affords an opportunity to represent the user's movements on screen. The attributes of VR in rehabilitation and skill development are well documented in the literature [4,5]. One of the most frequently cited drawbacks of VR remains cost. Beyond expense, some aspects of VR can be a mismatch with the user's preferences or abilities. Specifically, some learners can experience disorientation in full immersion, leading to compromised safety or triggering a sense of fear. Other learners may miss the full-body elements that are substituted when the VR environment removes the need to locomote through the environment. No single learning environment should suit everyone perfectly. Variability of training remains healthy and instructive. VR can be a complement to real-world contexts with wearables that can capture and report real-time or feedback performance, yielding a more direct transfer of training for some. In an effort to develop an optimal and personalized learning environment for each individual, the instructors (therapists, coaches and trainers) will benefit from having a means by which to capture their performance real-time, and in accumulation. It is additionally beneficial to have a means to deliver feedback in keeping with the learner's needs and preferences.

Finally, we need a means to measure their performance with precision - at the level of outcomes (field goal percentage, exit velocity, barreled ball, sway, gait speed), but also at the level of movement specifics. When our efforts include precise care (precision medicine, rehabilitation and skill-development), providers' should be using measurements to hold their interventions (training programs, therapeutic exercise, neuromuscular re-education) accountable. Wearables provide an exceptional source for such data. A singular unifying theme of this article should be taken that measurement provides an often-underappreciated part of intervention, through the gamified experience. Measurements afford the learner an opportunity to record a baseline, thereafter, compete against themselves, and continue to optimize the neuroplastic experiences inherent with learning, or refining, movement toward excellence (i.e. solving a movement problem). In an effort to improve our patients and athletes, is more information always better? Have we taken the notion that, "You cannot manage what you don't measure", too far? Are we capturing data for data's sake? Does the amount of data burden, rather than motivate us? Well outside of the realms of Olympic athletes, an increasing number of people are capturing data about their movement and body system function. Using a bracelet, watch or band the size of early pedometers, we can now (easily) measure or estimate steps per minute, calories spent, heart rate, heart rate variability, respiration rate, stories climbed, total minutes in standing, pulse oxygen and continuous blood glucose! This is not your grandmother's pedometer.

In a world filled with terms that were not in existence until technology brought them into existence, it may feel hard to keep up. Every sport has its collection of terms tied to previously invisible attributes of athlete performance. Where statistics once ruled the sports landscape and were often expressed in either volume or subjective human ratings (mph, yards after catch, seconds, hits, strokes, saves, shots on goal, assists and rebounds), the conversations pivoted in the 1980s to include sabermetrics comparing player values with consideration for reaction speeds, strategy, and situational performance. As if these analytics were not enough, the data collectors have "upped their game" again to include an entirely new vocabulary that would be unrecognizable by the 1980s fan that just started to tune-in to their favorite sport. The screens, broadcasts and training rooms are now filled with ubiquitous terms of spin rate, exit velocity, degree of difficulty and even load management. Nearly every sport uses cameras, wearables, microchips, sensors and global positioning satellites (GPS) trackers to provide more data than ever. However, in both between the lines (athletic competition) and in the confines (at home and work), there are psychological ramifications related to our plentiful access to data. An athlete's limited time already includes sport specific skills training, general conditioning, practice, competition, nutrition, recovery and other life-balance factors. Each factor can only occupy a limited piece of the athlete's time in the metaphorical human performance pie, as depicted in Figure 1.

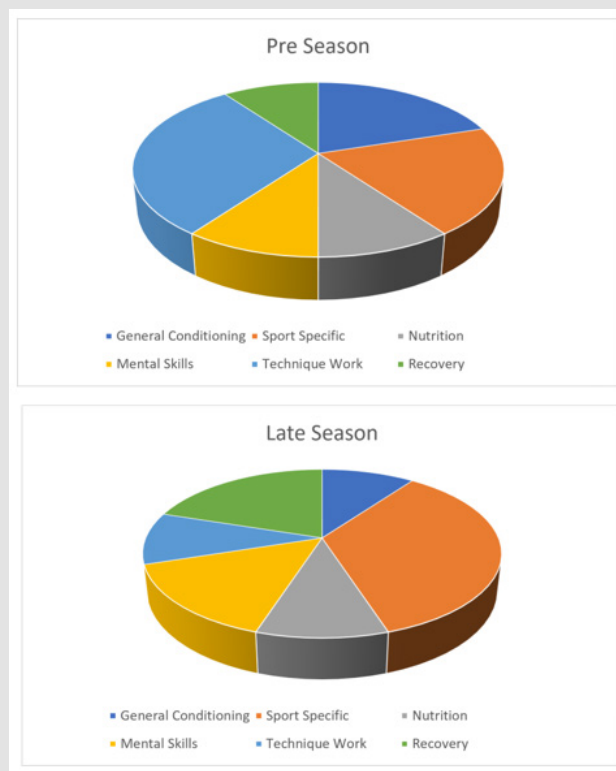


Figure 1.

We can train resources of psychological resilience, dual task tolerance, strength, power, reaction speed, agility, dexterity, endurance and balance; we need room for rest; we can refine movement (skill development) ...yet at some point this metaphorical pie cannot be divided up into more slices before something is under-dosed. We need value, not volume, from data. The best measurements are crafted so that they are a seamless and not disruptive part of the process. See Figure 1. The data should directly reflect the research question and consequent decision making (not just the documentation of it). Meaning, the most valuable data as a training ROI, rather than just being collected because it “can be measured” or measurement for measurement’s sake. This article will cover the spectrum of wearables, the psychological attributes that accompany being measured, as well as the pitfalls and gamification opportunities available. While it will be up to the reader to apply these concepts to their context and learner, the article will provide specific examples of gamification across athletic, vocational, rehabilitation and everyday life - affording movers of all speeds the best opportunity to gain through gamification, rather than drown-in, the data [6].

### The Ever-Expanding Spectrum of Wearables

#### Applications/Uses

Most motion capture wearables are capable of passively collecting a variety of data for later analysis. This can range from activity detection of an individual at fall risk or a person with Parkinson’s Disease where a medical and caregiver team would benefit from knowing total activity, recording falls and near-fall events as well as periods of freezing via remote capture. The same scenario could include in-person assessments of balance reflected by sway, gait speed, gait symmetry, and power in transitional movements [7]. Similarly, scouts and coaches could use the same accelerometers to capture physical performance (by volume of steps, speed (distance/time via GPS) or even accuracy of a task performed such as a ‘hit the target’ contest. Outcome variants of these tasks can be gradient: such as archery, golf and horseshoes where proximity-to-target matters in the context of

the sport, or they can be binary, as is the case in kicking a football or soccer ball through goal posts/into a goal or shooting a basketball through a hoop (where closeness doesn’t ‘count’). Still other related devices interact directly with the wearer by offering visual feedback (usually on an app) regarding raw data or calculated constructs. Examples of these sensors include devices that can be placed in a ball, bat, golf club or shoe insoles. Another emerging type of body-worn device that interacts with the user is fundamentally different from other wearables. This new technology can be attached anywhere on the body; however, its primary purpose is NOT only to measure motor behavior, but also to directly influence it.

The device offers real time augmented haptic and audio feedback assists in updating the wearer’s body model (proprioceptive) model, without needing the language processing centers of the brain as is required for verbal cues or metaphors. This sport and rehabilitative device ‘captures’ real time movements of the body part to which it is attached. It then compares that position or technique determined by the movement educator and gives the wearer immediate audio and haptic feedback based on their own real-time movements, in order to change or maintain a motor pattern. The service offered is the real time feedback; the collected data can be raw gradient or binary, or can offer a calculated construct such as an index of the ‘mastery of sensorimotor space’ - a kinesthetic awareness index. One potential way to categorize wearables is by location. Another means of categorization would include those that are worn daily (nearly continuously) that are built for general consumers versus those worn intermittently for sport training or rehabilitation. While we recognize other biophysiological data collection tools are valuable (e.g. continuous glucose monitoring and EEGs), this article will focus on small body-worn technologies intended to capture information about movement. While larger wearables, (exoskeletons), portable hand-held instruments (ultrasound), camera-based mobile apps and marked motion capture equipment can be effective - those will not be discussed here. See Tables 1 & 2 for a more comprehensive reflection of these options.

**Table 1:** Considerations for Wearable technology.

Category	Options Spectrum
Primary Purpose	Inform (objective only)
	Influence (subjective guidance or behavioral prompts)
Primary End Users	Athletes
	Coaches
	Trainers
	Medical professionals
Secondary Purpose	Diagnostic / Monitoring
	Predictive (for pre-decision support)
	Evaluative (post-activity/intervention assessment)
Question Types Answered	Binary (e.g., Should the wearer work out today?)
	Quantitative (e.g., How high did the wearer jump?)

Output Units	Raw Metrics (e.g., heart rate, breath count), ground force reaction, reaction time
	Calculated Constructs (e.g., HRV, load units, hydration index kinesthetic awareness tool index, center of Mass, center of pressure)
Activity Context	General wear (non-sport specific)
	Specific sessions (e.g., running, lifting)
	All-day use (e.g., step tracking)
Setting	Laboratory environments
	Real-world usage
Classification	Biochemical (e.g., hydration)
	Biomechanical (e.g., IMU data)
	Bio electrochemical (e.g., brain waves)
Mechanism	IMU (accelerometer, gyroscope, magnetometer)
	Infrared (light reflection)
	Electrical resistance (e.g., EMG (mV), EEG (ohms))
	Temperature, pressure sensors
Communication Style	Visual display (real-time or aggregated)
	Notifications (e.g., haptic, audio, beeping)
	On-screen graphics (e.g., color-coded feedback)
Output Delivery	Real-time / Immediate
	Delayed / Processed/Time series
Data Types	Motion capture (micro: torso, joints, limbs)
	Macro movement (yards, steps, GPS speed)
	Biometric (temperature, HR, HRV, hydration, blood sugar)
Placement on Body	Wrist
	Sternum
	Feet
	Torso
	Head
	Ear lobe
	Moveable between locations
Flexibility	Fixed location
	Moveable across the body
User Input Integration	Subjective input (e.g., mood, fatigue scales)

**Table 2:** This table includes a subset of terms from Table 1 Considerations for Wearable Technology. Not all terms included. Based on website 5/17/2025.

Company/Product	Website	In-form	Immediate Behavior Influence	Subjective Input Allowed	Designed for All-day Wear	Haptic	Motion Capture	Sensor Placement Fixed	Sensor Placement Moveable	Biochemical	Biomechanical	Bioelectrochemical
Catapult	<a href="https://www.catapultsports.com/">https://www.catapultsports.com/</a>	Yes	No	No	No	No	Yes	Yes	No	No	Yes	No

PantherTec KAT	<a href="https://panthertec.net/">https://panthertec.net/</a>	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No
Salted	<a href="https://sports.salted.ltd">https://sports.salted.ltd</a>	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No
Plantiga	<a href="https://plantiga.com/">https://plantiga.com/</a>	Yes	No	No	No	No	Yes	Yes	No	No	No	No
Output Sports	<a href="https://www.outputsports.com/">https://www.outputsports.com/</a>	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No
Emotiv EPOC X	<a href="https://www.emotiv.com">https://www.emotiv.com</a>	Yes	Yes	No	No	No	No	Yes	No	No	No	Yes
NeuroSky MindWave	<a href="https://neurosky.com/">https://neurosky.com/</a>	Yes	Yes	No	No	No	No	Yes	No	No	No	Yes
Mendi Headband	<a href="https://www.mendi.io">https://www.mendi.io</a>	Yes	Yes	No	No	No	No	Yes	No	No	No	Yes
EmWave	<a href="https://www.heartmath.com">https://www.heartmath.com</a>	Yes	No	No	No	No	No	Yes	No	No	No	No
Oura Ring	<a href="https://ouraring.com">https://ouraring.com</a>	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	No
WHOOP	<a href="https://www.whoop.com/">https://www.whoop.com/</a>	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	No
Fitbit	<a href="https://www.fitbit.com/">https://www.fitbit.com/</a>	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	No
Garmin	<a href="https://www.garmin.com/">https://www.garmin.com/</a>	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	No
NIX	<a href="https://nixbiosensors.com">https://nixbiosensors.com</a>	Yes	No	No	No	No	No	Yes	No	Yes	No	Yes
Kinvent	<a href="https://physio.kinvent.com">https://physio.kinvent.com</a>	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No
Novel	<a href="https://novelusa.com/pedar">https://novelusa.com/pedar</a>	Yes	No	No	No	No	No	Yes	No	No	Yes	No
DorsaVi	<a href="https://dorsavi.com/">https://dorsavi.com/</a>	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No

## Devices: what is this Device and where can we Place it on the Body?

Within the spectrum of wearables, there is a range of where they are commonly worn:

- **Wrist:** It is the most popular choice of location for placing accelerometers but has accuracy limitations across various activities. There is a great deal of variability in their accuracy at this location for pulse oxygen, respiration rate, VO2 max, and more.
- **Hip:** Hip placement is considered to be the most reliable for total steps/activity and body transitions due to its high accuracy.
- **Ankle:** Placing the sensor at the ankle is often beneficial for faster activities but should be used with caution while evaluating slower activities. Tracking devices worn on the ankle(s) are popular for running step and cadence as well as distance when paired with GPS.
- **Thigh:** Sensors placed on the thigh show good performance across various activities and are most widely used in running, jump analytics, change of direction, and in sport-specific applications as with a baseball pitcher.
- **Sternum or Back:** Tracking devices here can be attached directly (body tape) or worn in a halter. This location provides information about speed, acceleration, distance, change of direction, time in 'training zone'. Accelerometers placed on the sternum are popular in field sports with high load/fatigue/ injury prevalence concerns over a course of a season.
- **Head:** Impact sensors can be placed in a helmet that can monitor concussion risk. The newer technology allows for motion capture and simultaneous correction for keeping the head still in sports that require dynamic and precise interaction with a moving object such as a ball or puck.

It should be noted that some accelerometer systems include sensors placed in multiple areas of the body. Some act independently; others interact as a system of opals that may communicate with each other. These systems are most commonly in rehabilitative, gait and athletic endeavors.<sup>7</sup>

## Measurements Motivate: Defining Gamification in Points, Levels, Rewards, Streaks

The Merriam-Webster dictionary defines gamification as, "the process of adding games or gamelike elements to something (such as

a task) so as to encourage participation. [8]" While not included in this specific definition, it is commonly agreed that the game like features applied include points, levels, rewards, and leaderboards [9,10]. In their 2024 article entitled "Patient Choice and Motivators: Should behavioral economics inform the plan of care?", Studer and Shubert cite gamification as an effective tool to enhance motivation in the rehabilitation clinic [11]. More recently, the concept of streaks has been added to gamification, in the realms of psychology and most notably in behavior change. Streaks are particularly effective as they can encourage consistency of a behavior that is changing, toward becoming a habit, and eventually an identity. Continuing a streak is rewarded in a reductive if not over simplistic fashion through the dopamine circuitry in our brains, leading to an incentive to recapture this sensation again by fulfilling tomorrow's "streak" opportunity. We will address each of the pillars of gamification in this section, tying them back to the throughline of wearables.

### Points

Wearables capture data that can be seen in accumulation over a day or week and seen as "points" in the "game" of activity. This is most commonly the case with steps per day, flights, calories, and distance (mileage, kilometers).

### Levels and Leaderboards

Everyday wearables can capture data and assign levels, or ascribe consensus norms as levels. One common example of a level includes a fitness label assigned to a person's VO2 max. Another common example is crossing a significant left-digit marker for points such as 100 flights, 10,000 steps, or 10 hours of standing. Some integrated systems afford users the opportunity to compete real-time or in analog fashion, through groups and leaderboards as well.

### Rewards

Most typically an app or website associated with a wearable would award a badge or offer congratulations to a user for establishing a personal best in points or a new longest streak. The rewards may be displayed on the app or website and in some cases can be exchanged for other proprietary electronic rewards within the software. Common examples include a new bike jersey or helmet decal on stationary bike programs. Rewards can be arbitrarily assigned to and distributed at the discretion of the programmers for any of the other gamification pillars: points, levels or streaks. As rewards can be granted in an arbitrary fashion for most any achievement, this category is not represented in Tables 3-5 below.

**Table 3:** Examples of wearables leveraging gamification in health and wellness.

Daily mobility	Personal best number of flights ascended Continuous Glucose Monitor reading	Achieving World Health Organization physical activity standards (300 min/wk moderate activity)	5 days in a row, > 5000 steps
Rehabilitation	Best maximum gait velocity in recovery from stroke	Normal sway values for age/gender in quiet standing	No freezing episodes for 4 days in a row (person with PD)
Athletics	New PR for arm speed New PR for vertical jump	Averaged sub-5-minute mile for 5k Time in aerobic zone met	10 consecutive repetitions of acceptable movement pattern

**Table 4.**

Feedback Type*	Training Modes**	
<b>Positive:</b>	<b>Instruction:</b>	<b>Habit Break:</b>
Active Stimulus:	Audio and haptic feedback occurs when a desired motor behavior is achieved.	Audio and haptic feedback occurs only when the undesired motor behavior is replicated.
The wearer experiences audio sounds and haptic vibrations on the body part	Common in early cognitive stages of motor skill acquisition for understanding and conceptualizing the goal of the movement.	Common for increasing awareness in order to prevent an intermittent or subconscious motor pattern.
	Prompt is directed to “find the beeps” to achieve the ‘good’ motor pattern.	Prompt: Wearer is directed to “find the beeps” to avoid the ‘bad’ motor pattern.
<b>Negative:</b>	<b>Exploration:</b>	<b>Error Comprehension:</b>
Removal of Stimulus:	Audio and haptic feedback occurs continuously until the desired motor behavior is replicated.	Audio and haptic Feedback occurs continuously until the undesired motor behavior is replicated.
The wearer stops experiencing the audio and haptic vibrations on the body part.	Commonly used in later motor learning stages for creativity, adaptability and learning new pathways to solving motor problems.	Commonly used for increasing awareness and understanding and experiencing an intermittent or subconscious motor pattern, aka error exaggeration.
	Prompt: Wearer is directed to “find the quiet” to achieve the ‘good’ motor pattern. How many ways can you find the quiet and still achieve the outcome goal?	Prompt: Wearer is directed to “find the quiet” to experience an exaggerated version of the ‘bad’ motor pattern.

**Table 5.**

Company/Product	GPS	Accelerometer	Gyroscope	Heart Rate (PPG)	SpO2 Sensor	Temperature Sensor	EDA Sensor	IMU (Combined)	EEG	fNIRS	Pressure Sensor	Hydration Sensor	ECG	EMG
Catapult	Yes	Yes	Yes	No*	No	No	No	Yes	No	No	No	No	No	No
PantherTec KAT	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Salted	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
Plantiga	No	Yes	Yes	No	No	Yes	No	Yes	No	No	Yes	No	No	No
Output Sports	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	No
Emotiv EPOC X	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No
NeuroSky MindWave	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No
Mendi Headband	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No
EmWave	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No
Oura Ring	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	No	No

WHOOP	No	Yes	Yes	Yes	Yes	Yes	No*	Yes	No	No	No	No	No	No
Garmin*	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	No	No
NIX BioSensors	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	No
Kinvent*	No	Yes	Yes	No	No	No	No	Yes	No	No	Yes	No	No	Yes
Novel	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
DorsaVi	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	Yes

Note: \*Offers multiple products. Not all products have each sensor.

### Streaks

While streaks have only been recently considered to be a pillar of healthcare-based gamification, the popularity is well established in the psychology of behavior change. Continuing a streak of eating well, attending an exercise class, abstaining from alcohol or cigarettes are common examples in behavior change. For skill development, rehabilitation and wellness, the application of streaks is commonly seen either as individuals achieve a movement goal on consecutive days (ranging from steps to running mileage). In skill development applications where movement consistency is the goal, streaks can be particularly engaging in the form of consecutive repetitions without an error. Our attraction to competing against an established norm (level), our own personal best (points), or hitting another shot (streak), gamification is just one of the principles that motivates us to perform better...and want another repetition. While it is beyond the scope of this article to detail the concepts in the following list, readers are encouraged to consider the inherent value of each, using the associated references as needed:

- Flow and the Challenge Point Hypothesis [12-15]
- Near Miss Effect [16]
- Protection Motivation Theory [17]
- Loss Aversion [18]
- Endowment Effect [18]

Each of these are distinct concepts that can be leveraged to realize an enhanced (and healthy) relationship to our movement performance through the application of wearables. The movement educator has the responsibility of careful consideration of the athlete's age, physical, mental, emotional regulation and other developmental variables, along with actual skill level, peer skill levels, and phases of the sport's competitive periods (long or short tournament, pre-mid or post season, and individual motivation. Respecting each person as an individual, instructors of all types are best positioned when they have a variety of means by which to motivate. Some of these can include creating a "game within the game itself" (e.g. gamify), others can include competing to hold onto what you have (loss aversion18, Protection Motivation Theory17, the Endowment Effect18), and still other approaches can include developing a precise error or success

rate - a dosage of difficulty as would be the case with the Challenge Point Hypothesis.12 Wearables enter into all of these discussions, by providing an independent data source that is as real-time as we prefer and in the mode that this individual best learns through.

### You cannot Manage what you (did not) Measure

The well-known quote, "You cannot manage what you cannot measure." has been expressed in different iterations throughout time. The sentiment is most often attributed to the scientist Lord Kelvin, to the investor W. Edwards Deming, or to the educator and consultant Peter Drucker. No matter how it is written and no matter the source, there is a great deal of truth in the sentiment. While many have pointed out that this quote is not universally true, it would be difficult to suggest that in the case of movement. Movement that is measured can be improved more rapidly and completely, as compared to when it were not measured. Feedback about success, near-miss, and failed repetitions are well cited in movement literature and beyond - into the realms of psychology where we see the dopamine system's response to near misses is covered in depth [19-21]. As noted extensively in gambling and psychological literature, the near-miss effect is a natural human tendency - one that is yet to be sufficiently explored for human movement opportunities.

Wearables of all kinds give the learner a sense that:

- 1) Their movement matters
- 2) There is a science to skill development and rehabilitation - it has precision
- 3) I am being held accountable
- 4) We will soon know, without bias, if I am doing better than I used to

All of these internal dialogues comprise the beneficial effects of the art of measuring movement (in the background), using wearables.

### The Value of an Independent Third-Party Arbitrator

People that are learning a new skill, refining their current skill, or rehabilitating to regain prior skill, will (all three) benefit from external feedback. This is a well-established point in motor learning literature across sport, vocational and rehabilitative applications. A coach, supervisor, therapist or even well-informed parent might be

considered a biased source for this external feedback, a second party, if you will. Feedback that is generalized (knowledge of results) coming from this source may be discounted over time. Well-intentioned comments like: "Great job!", "You are doing so well!", "Good", "Hey, well done!", or "Yes!" can come too often and soon become meaningless to the learner. However, biofeedback from an external source such as a wearable may have greater effect or staying power if this feedback is considered to be unbiased. Hence, wearables can serve as an independent third-party arbitrator of sorts, reporting a score or value without secondary gain. If you provide coaching or rehabilitative care, it is likely that you have iterated one or more of these above-stated phrases hundreds of times in your career. You may have even iterated one of them hundreds of times to the same long-term patient or athlete! How helpful are any of these, coming from the same source, "on repeat"? The answer is likely, "not very". What is most important is the "opportunity cost". Opportunity cost is an established phrase, meaning, what is the cost (loss) incurred by using these same (or similar) phrases when you could have said or done something else? [22] That is an "opportunity lost" because of the choice to spend resources of time, energy, or capital - elsewhere. According to motor learning literature, these phrases may not be helpful at all. In some circumstances, saying something vacuous like, "Good" or "Great" can in fact detract from the learner's formation of their own internal reference or self-awareness about their performance. According to the work of Windt and colleagues (2020 - younger subjects in an athletic setting), as well as that of Peng and colleagues (2025 - geriatric subjects on exercise), some individuals that receive feedback from a wearable as an independent third-party arbitrator, we may be more likely to trust and be engaged by this source [23,24]. This concept deserves more depth as we search for precision care. A wearable can offer feedback is direct/countable (HR, Breath rate) or calculated (HRV, calories) or scaled constructs of performance/ readiness (i.e. red, yellow, green), The feedback is non-emotional, binary, and immediate: you did it or you didn't. This kind of objectivity creates a clean loop for error-based learning. One could spend a career studying the effects of the verbal cues, which can be immediately apparent in traditional instruction where the educator uses slightly different terms to exude a different movement. The educator also needs to consider the effects of the dose, type and timing non-verbal and haptic feedback in motor pattern acquisition. The benefit of objective feedback is that it inherently has no bias and no secondary gain that can easily come from any well-intentioned coach or therapist. Without belaboring the finer points on feedback in motor learning, it should be noted that it is healthy for people in skill development or in rehabilitation to receive a variety of feedback and sometimes no feedback at all. [25,26] This point was made effectively by two of the foremost authorities on motor learning, Drs. Gabrielle Wulf and Richard Schmidt in their 1994 paper, "Feedback-Induced Variability and the Learning of Generalized Motor Programs.". This finding and notion has been replicated by many authorities since [25-28].

## External Focus - Moving Attention Away from Movement

Both feedback frequency and source are significant in skill development and rehabilitation. Yes, that point has been made. However, there is another attribute of body worn sensors that can contribute to learning, and this is regarding attention, most specifically attentional focus. In their seminal paper introducing the Optimal theory of motor learning, Drs. Rebecca Lewthwaite and Gabrielle Wulf clarify the importance of focusing externally on a task to be accomplished, as compared to internally on the movement particulars. Meaning, "Did it go in?" is often more valuable than, "Did I achieve 30 degrees of wrist extension?". Many therapists, coaches and trainers alike will accept the notion that external focus (attention to task completion) is superior to internal focus (attention on movement quality and particulars) at all stages of learning and in all circumstances. This may be a reductive viewpoint, leaving out the all-too-important consideration of "why was I successful (or not) on this trial?". We may consider the question-and-answer pairing of, "Did it go in?" to be a more valuable data point than "Did I achieve 30 degrees of flexion", however there is a learning point in the middle of these two questions - a point that may ensure more consistent success in the future. The "middle question" is, "Was there a difference between what I intended, with what I did?". The difference between intention and action is both crucial to learning and often hard to capture. Movement is too fast (ballistic), comes in too many consecutive repetitions to break down (running form), or is too long ago (post-game review).

Learners benefit from error. Reward or success after error is the basis for the error-prediction model of motor learning. In some circles, this dopamine reward that is leveraged as a function of reward-prediction error, is the epitome of neuroplastic stimulus, creating a "tag" of significance for us to recall (fact, event, movement) for later consolidation in sleep that night. An analogy from sport may further clarify the importance of real-time errors, and a focus beyond "just" the win or loss. Consider the novice or inexperienced young bowler that is provided a lane with bumpers to prevent gutter balls. If the bumpers consistently prevent errors and allow for a wide range of movement variability, what does the child learn? While oversimplified and reductionist, one might surmise that the message is, "Success (external focus) will arrive, no matter the movement." If the bumpers are removed, or unavailable too early in learning, will the child feel defeated and lose interest, as the "wins" come rarely if at all? Would an intermittent experience that included a scheduled or even unpredictable, "bumpers on and bumpers off" serve the learner best? Is it possible that this is true for an adult learner, even a professional who is refining skilled movement? Feedback about why I was successful, in a bandwidth fashion, may be superior to the no failure (bumpers on) or full-failure (bumpers off) conditions. As we see in Table 3, wearables could provide auditory, visual or haptic feedback, either immediately or with some delay, signaling a successful trial or an aberration in movement.

By extension, skilled performers may not be able to progress or refine their movement if the primary feedback is the result (external focus). “How did I put that much \_\_\_ (spin, exit velocity, break) on the ball? How do I recreate that movement again for my \_\_\_ (swing, pitch, penalty kick, shot)? While some readers may see a possible contradiction forthcoming as wearables (most notably body worn accelerometers) may in fact provide information about how the movement was performed – knowledge of performance about the movement particulars. Does a tracker then increase attention to the movement particulars? No. In fact deferring specifics about the movement to the tracker can (and often does) reduce a learner’s tendencies to be attentive to the movement, as they can acquire this information after the movement, and either focus on either re-creating the last outcome (consistency of results) or recreate external kinematics (jump height, arm speed), and/or reproduce the sensation of movement that results in the desired outcome. Again, we see that the novice learner may need some movement specific advice; the more experienced learner may focus primarily on the result (walked safely, made the basket). However, the learning pendulum swings back again as the skilled learner may be approaching a ceiling effect and needs some movement-specific advice in an effort to improve from the last trial. In motor skill acquisition: essentially, the differences or comparisons (error signal) between:

- What I planned
- What I believe actually happened
- What the external monitor/wearable reports actually happened

The inherent differences can provide a stimulus for learning via recalibration. To an extent, we learn more from errors than successes - the exception being errors that occur repeatedly without our control or occur repeatedly in a context that we cannot seemingly either control or understand how to adjust. Thus, when errors are augmented beyond reality (we fail more than expected or the failure is exaggerated intentionally by the instructor (error augmented learning, perturbations, and some forms of method of error amplification. See chart of training modes using haptic feedback Appendix II. Error signals and “wins” from a wearable (can come real-time with haptics or sounds informing the learner about a successful trial or an error will increase attention to the movement. This elevated attention to a practice focus, a drill, has often been cited as the key mechanism by which we use success or error-filled trials and has been labeled deliberate practice. Perhaps the observation of the result (ball went in, time in 100m sprint, vertical jump height achieved, watts produced or mph of that pitch) when COMBINED with the externally-generated and real-time captured feedback from the tracker is the optimal combination. This “better together” may be superior to the binary feedback alone or the “did I achieve 30 degrees of flexion’ alone. We realize that optimal motor learning with results and performance feedback will

complement and respect the error-prediction models that have been supported in motor learning literature.

There are occasions, especially in sports, that:

1. The movement may be too fast to capture real time
2. The repetitions come too frequently to gain from the sensation generated

The sensory system continuously responds to environmental stimuli by attempting to reconcile discrepancies between perceived information from multiple sensory inputs and prior knowledge, a process facilitated by integration and inference. Artificially augmenting or drawing attention to a sensory conflict can expedite the resolution process. Specifically, when discrepancies arise between sensorimotor input and visual motor input, the typical resolution involves consciously altering motor patterns—adjusting the body’s movements to align the conflicting streams of information. An illustrative example of this occurs when an individual is instructed to touch the tip of their finger to the tip of their nose. To perform the task, they extend their arm forward, close their eyes, and attempt to make contact. Upon completion, the individual may realize they have instead touched the side of the nose, triggering an immediate urge to correct the movement and align the finger with the tip of the nose. This corrective action serves to resolve the conflict, and in doing so, updates the body’s spatial and temporal awareness. Within the context of motor learning, particularly when augmented with haptic feedback, this process also facilitates the remapping of the brain’s internal body model [29-31]. The distinction between the intended movement (“what I thought I did”) and the actual movement (“what I really did”) closely aligns with the error-prediction model in motor learning. Research suggests that errors, rather than successes, provide more substantial learning opportunities.

When errors are augmented beyond reality (we fail more than expected or the failure is exaggerated intentionally whether through instructor-driven techniques—such as in error-augmented learning, perturbation strategies, deliberate error amplification, and/or via a wearable body worn movement training device, the learning process is enhanced [32]. (See Appendix II for a chart outlining training modes utilizing haptic feedback with body) As many have written, philosophers and scientists alike, we can only evolve when we survive. This concept may have been first penned by Sir Charles Darwin (1859, *On the Origin of Species*) as he wrote, “It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.” [33]. Humans have previously found a primitive purpose in feeling productive, engaging in activities that promote our longevity, and engaging in activities that give us the opportunity to reproduce. We may sharpen our precision and accuracy in present times, yet very few of our contemporary movement-based decisions will lead to our demise. Therefore, we may need to facilitate the accuracy of our proprioception, gamifying the

learning with supplemental feedback. As with most any variable that can be added or removed, there is often “too much of a good thing”. Yes, we can receive too much feedback. The reverse is also true, without feedback, correction or error - there is very little room for us to learn. Feedback from wearables is no exception here. The prevailing concept of hormesis applies. Without feedback about our movement, we may be destined for overuse injury (same pattern of movement, “arm slot” in pitching with cumulative effects), or may never find how to achieve that velocity or spin rate again “how did we do that?”. With too much feedback, we can become reliant on an external source and have no internal reference from which to build upon (innovate) or to find again if the source of feedback is not available (practice vs. game, changed coaches).

### Placebo vs. Placebo Effect

Many people misconstrue these terms to be the same. A placebo is a sham, something that is estimated to have no value, yet (often) is introduced as a plausible solution. We will leave the imprecise science about placebos out of this article as this has been covered well elsewhere, most notably by Allie Crum and Ellen Langer in their 2007 article [34], and subsequently by many others [35,36]. In contrast, the placebo effect refers to the power of or benefit received from believing in an intervention, product, or person. The placebo effect describes the increase, or improvement, yet does not intend to assign value to the intervention, product, or provider. The placebo effect can “make a good thing better” or improve the efficacy of an intervention that has a proven physiologic basis (evidence) for its actions, beyond belief. It is important to place these qualifiers “physiologic basis beyond belief”, as even belief has a physiology – through neuromodulators and neurotransmitters that can cause us to form an implicit bias and anticipation of reward. Recently, in the field of behavioral economics, the “halo effect” has drawn comparisons to the placebo effect as through the natural human tendency of implicit bias we assign values that are as yet unearned by someone or something due to our own preferences or beliefs. To be clear, the placebo effect will influence our perception of an intervention (drill, task, practice, weight, constraint) and change our perception of a sensation such as effort or pain.

Very closely related is the halo effect which may have the same far-reaching outcomes but operates through our belief in the deliverer, which could include a coach, therapist, surgeon or trainer. Both will influence our perceptions. In yet one other related and well described concept, the placebo effect will draw comparisons to the Hawthorne effect, which can be described as the benefit realized when an individual is aware that they are being measured. Bringing this full circle, we realize that the introduction of technology may be deemed as a positive attribute, giving the learner the impression that leads to a placebo effect and additionally a halo effect and finally a Hawthorne effect as we wield the technology, indicate an increased level of sophistication, provide objective (irrefutable) information, and demonstrate the ability to capture measurements. Is it ethical, warranted, or

perhaps even compulsory for providers in healthcare and wellness to leverage the placebo effect? Meaning, patient belief, patient buy-in... how different are these from patient engagement and self-efficacy? Would it not be indicated in every possible situation to benefit from the power of (the recipient) believing in an intervention? When that intervention has evidence and is indicated for this person (precision medicine, rehabilitation, wellness), we want and expect the recipient to believe in the care. As we learned in the section entitled, “Third Party Arbitrator”, feedback that comes from an unbiased source can be more easily accepted to be without bias. Wearables of all kinds may be able to demonstrate accountability, thereby elevating belief, or the placebo effect if you prefer. The same intervention with and without belief may have dramatically different outcomes even when all other conditions are held constant.

### Wearables’ Effects on Motor Learning: Dopamine, Intensity, Attention, Plasticity

Let us be perfectly clear that no two people have identical profiles in these three variables: life experiences, learning capacities and learning styles. The addition of technology in the form of wearables therefore cannot be expected to have a uniform effect on all persons. As noted above, wearables may boost an outcome. Through the placebo effect, the halo effect, and the Hawthorne effect. In this section, we will briefly review the proposed physiology that may lead an individual to learn more quickly and when utilizing wearables. Readers are encouraged to further explore each term, using the associated references as needed:

Dopamine (a neurotransmitter involved in reward) is a critical component in motor learning, affecting motivation, error correction, movement initiation, neuroplasticity, and persistence [37-40]. It helps the brain reinforce successful motor actions, adapt to errors, and optimize movement patterns over time. By influencing these processes, dopamine enables efficient motor learning and skill acquisition. High-intensity practice enhances neural activation and can help fine-tune coordination and timing of movements especially in tasks requiring precision and speed. It can boost motivation, as learners see quick progress and experience more rewarding feedback. Training at higher intensities also can help learners maintain motor performance under fatigue, mirroring real-world conditions. and may improve the ability to apply skills transfer. In the early stages of learning, lower intensity is used to focus on basic skills, while higher intensity is gradually introduced as skills become more refined and automatic.

Attention plays a central role in motor learning by directing focus to relevant aspects of the task, managing cognitive resources, and processing feedback to refine movement patterns. The ability to focus both internally and externally, as well as to maintain concentration during practice, directly influences the effectiveness and speed of motor skill acquisition. Synaptic Plasticity – The properties of a connection that are subject to change, based on patterns of repeated neu-

ronal firing (practice) or lack thereof. Long Term Potentiation (LTP) - A physiological process by which humans learn. Primarily studied in the hippocampus. LTP is evidenced when the same amount of stimulation at a pre-synaptic cell produces an increased amount of activity in the post-synaptic cell after repeated electrochemical exchanges (repetitions) in the synapse.

## Conclusion

There are many types of wearables available, and more in the pipeline to be developed. Cumulative data and real-time information coming from these devices can supplement the wellness, skill development, and rehabilitation experiences. These devices can enhance motor learning, rehabilitation, and performance by providing real-time, personalized feedback that engages users through gamified elements. However, the impact of these technologies depends on the appropriate timing as well as the integration of data, feedback, and engagement strategies tailored to the individual – the person – the end user upon which all precision care depends. Wearables have the potential to optimize neuroplasticity and skill development through reward systems and in shaping the accuracy of movement that leads to a desired result. The benefits of wearables must be balanced and personalized to the preferences of the user. After reading this article, providers in the healthcare, wellness, and skill-development sectors alike should feel well positioned to personalize which wearable and what data will provide the optimal experience for the individual that they are privileged to help.

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