Intrigue AI: The next evolution of ear-level fitness trackers with accurate step counting and activity classification

Jingjing Xu, Ph.D., Michelle Hicks, Ph.D.

The Audibel Intrigue AI platform, equipped with state-of-the-art sensor and artificial intelligence technologies, provides more accurate step counts than its predecessor and two popular wrist-worn fitness trackers based on a standardized test. In addition, the Intrigue AI platform was the first in the hearing aid industry to offer accurate classification of physical activities. This evolutionary ear-level fitness tracking feature allows hearing aid wearers to monitor their physical activities for maintaining physical health and well-being.

Introduction

Regular physical activity is critical for maintaining a healthy lifestyle. A guideline from the U.S. Department of Health and Human Services recommends that adults aged 65 years and older need at least 150 minutes a week of moderate-intensity activity, such as brisk walking, or 75 minutes a week of vigorous-intensity activity such as hiking or running *(Piercy et al., 2018)*. While regular physical exercise can reduce health-related risks and improve some health conditions *(Myers, 2003)*, it may be especially important for individuals with hearing loss *(Stickel et al., 2021)*. Research in epidemiology has shown that moderate and greater degrees of hearing loss in older adults are associated with decreased levels of physical activity *(Gispen et al., 2014)*. Therefore, hearing impairment and increased risks of compromised health conditions could make older adults with hearing loss one of the more vulnerable populations in our society in terms of health outcomes.

Using a fitness tracker to monitor physical activities can raise awareness of activity levels, which may in turn motivate individuals to be more active in their daily lives *(Bravata et al., 2007; Chapman et al., 2016)*. Currently, wrist-worn trackers are the most popular devices. The Pew Research Center reported in 2020 that one in five Americans regularly used a wrist-worn fitness tracker *(Pew Research Center, 2020)*.

Hearing aids are the primary intervention for individuals with sensorineural hearing loss. They sit in the wearer's ears during most of the active hours of the day, which provides a great opportunity to track daily physical activities. Recent technological advances in hearing aids, embedded motion sensors, and machine learning allow for fitness tracking. Audibel was the first in the hearing-aid industry to introduce an Inertial Measurement Unit (IMU) motion sensor into their hearing aids to track step counts as a part of a physical health score.

The recently released Intrigue AI hearing aids equipped with a new IMU motion sensor and a newly developed machine learning-based algorithm allow wearers to track not only their steps, but also their physical activity type and exercise duration while using hearing aids for listening in daily situations.

The Next Evolution in Fitness Tracking

All of Audibel Intrigue AI 2.4 GHz hearing aids utilize IMU sensor technology. This is the next evolution in activity tracking in hearing aids that goes beyond previous Audibel devices by introducing an algorithm for categorizing different physical activities, developed via machine learning. Specifically, a large amount of accelerometer data from the IMU sensor was gathered from hearing aid wearers performing various physical activities; then, Gaussian Mixture Models (GMMs) and Linear Support Vector Machines (SVMs) were trained on this data to learn the patterns of these activities. The Intrigue AI algorithm relies on these learned patterns to identify when a wearer is standing, walking, or running.

In addition to activity classification, the IMU in the hearing aid counts steps when performing physical activities. Its accuracy was gauged by following the procedures described in a standard by the American National Standards Institute (ANSI) and Consumer Technology Association (CTA) (ANSI/CTA-2056, Consumer Technology Association, 2016). This standard presents definitions and performance criteria for measuring step-count accuracy on consumer wearable or app-based physical activity monitoring devices, as well as guidelines for evaluating and comparing step-count accuracy across different fitness tracking devices.

In this article, we will present data to demonstrate the accuracy of physical activity classification and step tracking with Intrigue AI hearing aids.

Activity Classification

The objective of the activity classification feature is to accurately differentiate and classify different types of physical activities. A study was conducted to evaluate the accuracy of activity classification. The participants in this study were 20 adults, aged 22 to 58 years (Mean = 38.2, SD = 9.3), without any self-reported physical disabilities. Each participant wore a Intrigue AI rechargeable receiver-in-canal (RIC RT) device on the right ear and a previous generation rechargeable RIC device on the left ear. These hearing aids were programmed for a 20 dB HL flat loss. The participant was asked to perform a series of activities in a gym, including walking, running, stationary biking, lying down, sitting/standing, and aerobics (jumping jacks and squats) for a specified period of time.

The physical activity classes, test durations, and sensitivity and specificity values for the Intrigue AI activity classification feature are listed in Table 1. The sensitivity of the feature measures that the probability of the performed activity is accurately identified by the feature. The specificity of the feature measures that the probability of the non-performed activity is not identified by the feature. For example, when hearing aid wearers performed 5 minutes of walking 100 times, the walking activity was identified 95.65 times (sensitivity); when hearing aid wearers performed activities other than walking 100 times, the walking activity was not identified 98.95 times (specificity). Performance of the activity classification feature is shown in Table 1. For all the typical physical activities that were tested, the sensitivity and specificity values were greater than 90, indicating that the feature classifies physical activities with high accuracy.

ACTIVITY CLASS		DURATION (MINUTES)	SENSITIVITY	SPECIFICITY
Walking		5	95.65	98.95
Running		5	90.32	99.92
Biking		4	92.96	97.96
Lying down		4	98.29	98.98
Sitting and standing		1	93.87	99.65
Aerobics	Jumping jacks	1	99.32	99.70
	Squats	1		

Table 1: Sensitivity and specificity of the physical activities measured and tracked in the My Audibel app

In addition to classifying different physical activities, the activity tracking feature will also measure and report on the amount of time spent exercising (which is the total time spent brisk walking, running, biking, and completing aerobic movements) and the total step count throughout the day. These data are displayed in the My Audibel mobile application using the "Health" tab found at the bottom of the screen (Figure 1).

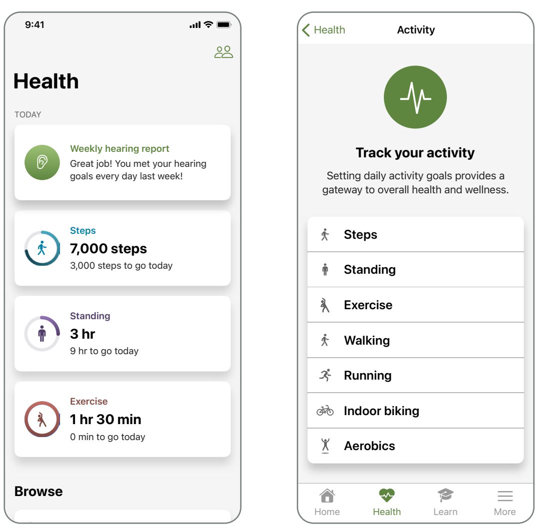

Figure 1: The information of physical activity displayed in the My Audibel app for Intrigue AI hearing aids

Step Count Accuracy

The participants in this part of the study were 20 adults (17 of them participated in the activity classification evaluation), aged 23 to 54 years (Mean = 36.4, SD = 8.4) without any self-reported physical disabilities. The hearing aids used for this measurement were the same as those for the activity classification measurement. In addition, the participants wore two popular smart watches with fitness tracking capabilities. Data collection procedures specified in ANSI/CTA-2056 were strictly followed. The participant was instructed to walk and run naturally on a treadmill at a 0% incline for 5 minutes. Walking speed was between 2.5 and 4 mph and running speed was between 5 and 12 mph. Video recordings of each activity were taken using a Samsung Galaxy S5 smartphone to allow for the most accurate manual counting of steps. Following the study visit, the participant's actual step count was manually counted and served as the ground truth to which each of the activity tracker values were compared.

Figure 2 shows the step count differences between readings from the four devices and their corresponding actual step counts. In this box-and-whisker plot, the boxes show the data range between 25 and 75 percentiles while the solid line inside the box denotes the median or the 50-percentile value.

The whiskers show the minimum and the maximum non-outlying values. The value of 0 on the y-axis means the step count reading from a tracker equals to the actual step count. Figure 2 shows that the difference values for the Intrigue AI device are closest to zero compared to the previous generation hearing aid and two smart watches for both walking and running. A within-subjects repeated measures ANOVA model was used to compare the differences values across the four devices. There was one within-subjects variable: Device (Four levels: Intrigue AI, previous generation hearing aid, Watch 1, Watch 2). For walking, the main effect of Device (with Greenhouse-Geisser correction) was significant ($F(2.16, 41.04) = 5.102$, $p = 0.009$). Paired comparisons with Bonferroni correction showed two significant comparison differences. First, the difference values for the Intrigue AI device were significantly smaller (more accurate) than those for the previous generation device ($p = 0.044$), and second, the difference values for the Intrigue AI device were significantly smaller (more accurate) than those for Watch 2 ($p = 0.048$).

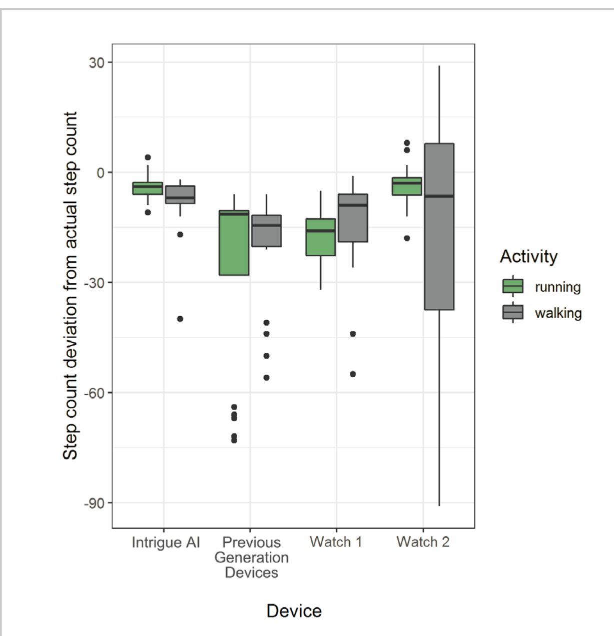

Figure 2. Distribution of step count deviation from actual step count for 5 minutes of running and 5 minutes of walking. A positive value means the step count value from a device is greater than the corresponding actual step count.

For running, the main effect of Device (with Greenhouse-Geisser correction) was significant ($F(1.2, 22.8) = 10.429$, $p = 0.002$). Paired comparisons with Bonferroni correction showed multiple significant differences: (1) the difference values for the Intrigue AI device were significantly smaller (more accurate) than those for the previous generation device ($p = 0.009$), (2) the difference values for the Intrigue AI device were significantly smaller (more accurate) than those for the Watch 1 ($p < 0.001$), (3) the difference values for Watch 2 were significantly smaller (more accurate) than those for the previous generation device ($p = 0.016$), and (4) the difference values for Watch 2 were significantly smaller (more accurate) than those for the Watch 1 ($p < 0.001$). Taken together, for running, Intrigue AI and Watch 2 were the top two in terms of step count accuracy and they were not statistically different.

Another way to interpret the step tracking data is to calculate the mean deviations between the activity tracker step counts and the actual step counts per 100 steps (Table 2) for each device. For example, out of 100 steps of walking, the Intrigue AI hearing aids deviated on average by +/- 1.5 steps. The observed pattern of results based on this type of analysis follows the same trends as the previous analysis. Namely, Intrigue AI was more accurate at step counting than the previous generation devices and Watch 1, and comparable in its accuracy of step counting to Watch 2.

	Intrigue AI	**Previous Generation**	**Watch 1**	**Watch 2**
Walking	1.5	3.5	2.5	4.7
Running	0.6	2.9	2.0	0.7

Table 2: Mean absolute step difference from the actual step count per 100 steps

The ANSI/CTA-2056 standard uses mean absolute percentage error (MAPE) to quantify measurement accuracy, which is calculated based on the difference between the actual step counts and the activity tracker step counts. The following equation describes the calculation of MAPE (Equation 1):

$$MAPE = \frac{100}{n} \times \sum_{i=1}^{n} \left| \frac{T_i - E_i}{T_i} \right|$$

Equation 1: MAPE calculation, where n is the number of participants; Ti is the actual step counts obtained from the manual step count from the video for each participant; and Ei is the value obtained from the tracker for each participant.

A lower MAPE value indicates a more accurate measurement. MAPE values for all the test devices are listed in Table 3. According to the ANSI/CTA-2056, the acceptance criterion is that the MAPE value shall be within 10% for both walking and running. The data in Table 3 show that all four devices meet the acceptance criterion. The Intrigue AI device has the lowest MAPE values for both walking and running, indicating the most accurate step counting performance.

	Intrigue AI	**Previous Generation**	**Watch 1**	**Watch 2**
Walking	1.49	3.48	2.5	4.65
Running	0.56	2.93	2.05	0.65

Table 3. Step tracking accuracy quantified by mean absolute percentage error (MAPE). A lower MAPE value indicates a more accurate measurement.

Discussion and Conclusions

The data from the present study demonstrates that Intrigue AI hearing aids with embedded IMU sensor and machine learning-based activity classification algorithm can provide accurate physical activity classification and step tracking. Accuracy in activity tracking is an important element to encourage the use of fitness tracking capabilities in hearing aids and motivate physical activity.

An evaluation of step-count accuracy following the procedures outlined by ANSI/CTA-2056 indicates that Intrigue AI hearing aids are highly accurate in counting steps during running and walking activities, compared to the previous generation hearing aids and two of the more popular, commercially available, wrist-worn fitness trackers. Step count accuracy of previous Audibel hearing aids has been reported in the literature. An independent study by Rahme et al (2021) compared step-count accuracy with a Audibel Via AI hearing aid, a Fitbit Charge 3 tracker, and a waist-worn pedometer. In that study, the Via AI hearing aid recorded the most accurate step count among the three devices. The current study expanded upon this previous work with a newer sensor platform, a newly developed activity classification feature, greater number of participants, and a standardized procedure for assessing step-count accuracy. The results of accurate activity classification and step counting with the Intrigue AI hearing aids further support the feasibility of using hearing aids as a fitness tracker.

The high degree of accuracy in step tracking demonstrated with the Intrigue AI hearing aids can be attributed to sensor and machine learning technologies, which rely on precise movements of the hearing aid user's body to detect steps. In contrast, wrist-worn fitness trackers rely largely on arm motion for step detection. Their accuracy could be compromised for people who use a walker or a cane, hold handrails on a treadmill while doing exercises, as well as for those who have reduced arm swing caused by diseases or disorders, such as stroke, Erb's palsy, and Parkinson's disease *(e.g., Mirelman et al., 2016)*. Moreover, wrist-worn devices may record false steps while the wearer is stationary yet moving their arms (e.g., working at a desk).

Hearing healthcare professionals know that successful rehabilitation is not limited to amplification devices and includes communication strategy training and other information specific to the patient's needs. This additional information may include addressing the greater health status of the individual seeking help with hearing (Saunders et al., 2021). Activity sensors and app support in smartphones may provide additional motivation to increase activity, which may reduce the detrimental effects of sedentary lifestyles known to be associated with hearing loss. Intrigue AI hearing aids with embedded sensors and machine learning can provide accurate physical activity tracking. With industry-leading hearing loss compensation technologies and fitness tracking integrated into one device, hearing aid wearers can not only hear better, but also live better by monitoring their physical activity levels to improve their general health and well-being.

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Author Biographies

Jingjing Xu, Ph.D., is a research scientist in the department of clinical and audiology research at Starkey. Before joining Starkey in 2016, he was a research assistant professor of audiology at the University of Memphis. He received his Master's degree in Engineering Acoustics from the Technical University of Denmark and his Ph.D. in Communication Sciences and Disorders from the University of Memphis. His research interests include acoustics, speech recognition, hearing aid outcome measures, and ecological momentary assessment.

Michelle Hicks, Ph.D., is Vice President of Education and Audiology at Starkey. She currently leads a team of audiologists and hearing professionals responsible for clinical and audiology research, as well as product and feature validation of new hearing aid products and accessories. She joined Starkey in 2010 and has over 22 years of experience in clinical practice, research, education, and industry. Dr. Hicks received her Ph.D. in Speech and Hearing Science in 1997 from Arizona State University and has presented at state, national, and international conferences on topics including Hearing Science, Amplification, and Tinnitus.