

Review

Analysis of the Results of Heel-Rise Test with Sensors: A Systematic Review

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Abstract: Strokes are a constant concern for people and pose a major health concern. Tests that allow detection and the rehabilitation of patients have started to become more important and essential. There are several tests used by physiotherapists to speed up the recovery process of patients. This article presents a systematic review of existing studies using the Heel-Rise Test and sensors (i.e., accelerometers, gyroscopes, pressure and tilt sensors) to estimate the different levels and health statuses of individuals. It was found that the most measured parameter was related to the number of repetitions, and the maximum number of repetitions for a healthy adult is 25 repetitions. As for future work, the implementation of these methods with a simple mobile device will facilitate the different measurements on this subject.

Keywords: physical therapy; mobile devices; technology; sensors; Heel-Rise test

1. Introduction

The combination of information technology with tests associated with physical therapy over time has been growing gradually [1–4]. The emergence of different sensors related with the study of movement, including inertial, magnetic, and force sensors, allows the measurement of varying parameters related to movement including its duration [5–11]. Thus, it is possible to create patterns to audit and standardize degrees and levels of certain diseases.

The evolution of the sensory technology allowed the creation of sensors in reduced size with increased efficiency in different types of measurement [6,12–15]. Mobile devices are growing in the existence of development frameworks to facilitate the programming of different functions and the increasing power processing and capabilities of these devices [16–20]. From this moment on, innumerable studies started to be developed with different tests associated with physical therapy to instrumentalize them [21–23].

The Heel-Rise test intends to test the function of the calf muscle–tendon unit, used to evaluate the resistance and strength of this muscle and chronic venous disorders [21,24,25]. Sensors, such as a pressure sensor, can be vital, because they can analyze the power that the individual performs during the exercise, providing some essential indicators. The Heel-Rise Test consists in the repetition of the elevation of the heel several consecutive times, until the subject is fatigued. The usual number of successive elevations before the subject is exhausted is around 25 repetitions as presented in Figure 1.



Figure 1. Performance of a Heel-Rise repetition.

This systematic review intends to analyze existing studies in the literature that used the Heel-Rise Test as a means of investigation for the calculation of features, presenting the results and subsequent conclusions.

The results showed that the use of sensors improve the measurements of the results of Heel-Rise Test. Different technologies may be implemented, but the most used are pressure sensors. The most measured parameters are Heel-Rise repetitions, ankle range of motion, Heel-Rise height, Heel-Rise work, and limb symmetry index (LSI). In general, healthy adults can perform 25 repetitions at the time of the test.

Next, Section 2 presents the methodology of the study. The results are presented in Section 3, the results are discussed in Section 4. Finally, Section 5 presents the conclusions of this study.

2. Methods

2.1. Research Questions

The main research questions of this review were as follows: (RQ1) How to measure the Heel-Rise Test with sensors? (RQ2) Which features extracted from the different sensors may support the analysis of the results of the Heel-Rise Test? (RQ3) How to improve the measurement of the Heel-Rise Test in the future?

2.2. Inclusion Criteria

The methods available in the literature for the measurement of the results of Heel-Rise Test and the inclusion criteria of the searched studies were: (1) studies that measure the effects of Heel-Rise Test using sensors; (2) studies that extracted different features related to the Heel-Rise Test; (3) studies published between 2010 and 2020; (4) studies that present the population involved and results obtained; and (5) studies written in the English language.

2.3. Search Strategy

There are different scientific libraries available electronically that were used for this research. The team used the following electronic databases: ACM Digital Library, IEEE Xplore, PubMed, ScienceDirect, BioMed Central, and National Institutes of Health with the help of the Natural Language Processing(NLP)-based framework described in Reference [26]. The keywords used for the research for this systematic review were: “Heel-Rise Test” and “sensors”. Each scientific article found in the study was independently analyzed, included, and excluded by the agreement of three reviewers. This research intends to explain the different papers related to the measurement of the analysis performed with the Heel-Rise Test using various sensors. This research was conducted on 8 June 2020.

2.4. Extraction of Study Characteristics

The selected and analyzed studies are tabulated in Table 1, presenting the year of publication, location, the population of the study, purpose, sensors used, and diseases present in the studied population. Generally, the raw data and source code of the analysis of the results of the Heel-Rise Test available in the literature are not publicly shared. However, we contacted the corresponding authors to obtain more precise information about the different analysis and results reported. There are a small set of sensors used, and this subject needs more research.

Table 1. Study analysis.

| Study | Year of Publication | Location | Population | Purpose | Sensors Used | Diseases |
|-------------------------|---------------------|--------------------------|--|--|--|--|
| Bayer et al. [27] | 2018 | Denmark | 50 patients with unknown age | Examination of the relation between tissue perfusion and morphological changes of the muscle | MuscleLab measurement system | hamstring injuries, calf injuries, and quadriceps injuries |
| Eliasson et al. [28] | 2018 | Denmark | 75 patients aged between 18 and 65 years old | Examination of whether tendon elongation, mechanical properties, and functional outcomes during rehabilitation | MuscleLab measurement system | Achilles tendon ruptures |
| Byrne et al. [29] | 2017 | United Kingdom | 38 participants aged between 27 and 45 years old | Comparison of the intrarater test–retest reliability and measurement agreement with standard device | MuscleLab measurement system | Healthy people |
| Brorsson et al. [30] | 2016 | Sweden | 101 patients aged between 18 and 65 years old | Evaluation of the ability to perform standardized seated Heel-Rises after an Achilles tendon rupture | MuscleLab measurement system | Achilles tendon ruptures |
| Nawoczinski et al. [31] | 2016 | Unites States of America | 14 patients with unknown age | Determination of the effect of an isolated gastrocnemius recession procedure on ankle power and endurance | Flock of Bird 6 degree of freedom electromagnetic sensor motion capture system | Achilles tendinopathy |
| Tengman et al. [32] | 2015 | Sweden | 52 participants aged between 37 and 58 years old | Evaluation of muscle fatigue | Electromyography | Achilles tendon ruptures |
| Olsson et al. [33] | 2014 | Sweden | 93 individuals with mean age of 40 years old | Study of the symptoms maximum Heel-Rise height for function | Linear encoder | Achilles tendon ruptures |
| Neville et al. [34] | 2013 | Unites States of America | 30 subjects with unknown age | Comparison of total and distributed loading patterns in subjects with stage II Tibialis Posterior Tendon Dysfunction | Capacitive sensors | Stage II tibialis posterior tendon dysfunction |

Table 1. Cont.

| Study | Year of Publication | Location | Population | Purpose | Sensors Used | Diseases |
|------------------------------|---------------------|--------------------------|---|--|------------------------------|---------------------------------|
| Robbins et al. [35] | 2013 | United Kingdom | 10 male subjects aged between 22 and 32 years old | Determination of whole-body vibration on the myoelectrical activity of selected plantar flexors | Power Plate pro | Healthy people |
| Bicici et al. [36] | 2012 | Turkey | 15 male subjects aged between 18 and 22 years old | Evaluation of functional performance in athletes | Tilt sensors | Chronic inversion ankle sprains |
| Silbernagel et al. [37] | 2012 | Unites States of America | 18 participants aged between 20 and 59 years old | Evaluation of side-to-side differences in maximal Heel-Rise height | Linear encoder | Achilles tendon ruptures |
| Olsson et al. [38] | 2011 | Sweden | 81 individuals with unknown age | Evaluation of the results after an acute Achilles tendon rupture | MuscleLab measurement system | Achilles tendon ruptures |
| Nilsson-Helander et al. [39] | 2010 | Sweden | 97 individuals with mean age of 41 years old | Comparison of outcomes between patients | MuscleLab measurement system | Achilles tendon ruptures |
| Silbernagel et al. [40] | 2010 | Sweden | 78 subjects aged between 33 and 51 years old | Evaluation of the validity and ability to detect differences in outcome of a Heel-Rise work test | MuscleLab measurement system | Achilles tendon ruptures |
| Vuillerme et al. [41] | 2010 | France | 18 healthy male adults aged between 24 and 28 years old | Assessment of the capacity of the central nervous system | Pressure sensors | Healthy people |

3. Results

As shown in Figure 2, we identified 87 studies from the selected databases, of which five papers were duplicates. After the analysis of the title, abstract, and keywords of each scientific article, 47 articles were discarded from the analysis because they are not directly related to the evaluation of the Heel-Rise Test with sensors. The remaining 35 studies were evaluated by the relation of the inclusion criteria and its full text, where 20 studies were excluded, and 15 articles were included, examined, and involved in the qualitative and quantitative syntheses.

After the selection of the different studies, the relevant information, and various metadata were extracted. For further detailed information, the readers should refer to the original cited works about the analysis of the Heel-Rise Test with sensors. Following our research, finding studies published between 2010 and 2020, and the information reported on Table 1, three studies (33%) were published in 2010, one study (7%) was published in 2011, two studies (13%) were published in 2012, two studies (13%) were published in 2013, one study (7%) was published in 2014, one study (7%) was published in 2015, two studies (13%) were published in 2016, one study (7%) was published in 2017, and two studies (13%) were published in 2018. The sensors used were also analyzed, verifying that seven studies (47%) used the MuscleLab measurement system, one study (7%) used pressure sensors, one study (7%) used the Flock of Bird 6 degree of freedom electromagnetic sensor motion capture system, one study (7%) used electromyography sensors, two studies (13%) used linear encoder, one study (7%) used capacitive sensors, one study (7%) used Plate plane pro, and one study (7%) used tilt sensors. Following the diseases of the population of the study, eight studies (53%) analyzed patients with Achilles tendon ruptures, one study (7%) examined individuals with chronic inversion ankle sprains, one study (7%) examined individuals with hamstring injuries, calf injuries and quadriceps injuries, one study (7%)

examined individuals with Achilles tendinopathy, one study (7%) examined individuals with stage II tibialis posterior tendon dysfunction, and the remaining three studies (20%) analyzed healthy people. Following the location of the different studies, six studies (40%) were performed in Sweden, two studies (13%) were performed in Denmark, two studies (13%) were performed in United Kingdom, three studies (20%) were performed in United States of America, one study (7%) was performed in Turkey, and the remaining study (7%) was performed in France.

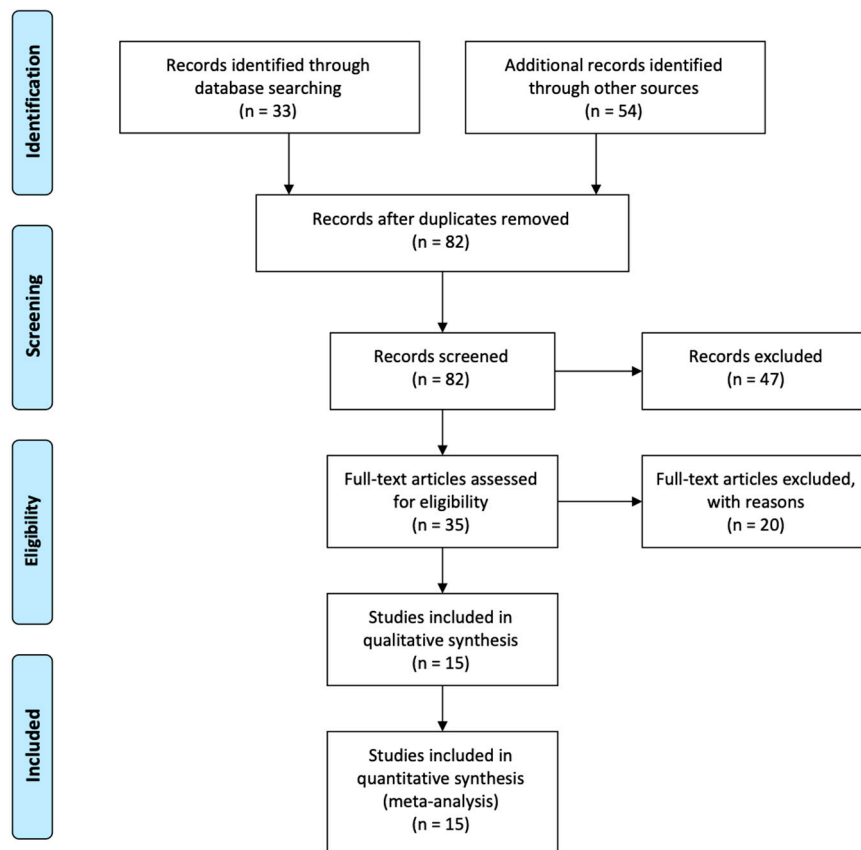


Figure 2. Flow diagram of the selection of the papers.

Based on data acquired from the pressure sensor, the authors of Reference [41] extracted different features, including the weight-bearing index, the surface area covered by the trajectory of the center-of-pressure, and the mean speed of the center-of-pressure displacements. All features were extracted and compared from the non-dominant or non-fatigued leg, and the dominant or fatigued leg. The implemented methods for the analysis of the different data were the Kolmogorov–Smirnov test, and the one-way analysis of variance (ANOVA). Finally, it is verified that the variance of the weight-bearing index did not show differences. Also, the post-test condition revealed an increased center-of-pressure surface area under the dominant fatigued leg and the non-dominant non-fatigued leg, a reduced center-of-pressure surface area under the non-fatigued leg relative to the fatigued leg, and an increased mean speed of the center-of-pressure surface area under the fatigued leg.

Based on the data acquired from MuscleLab [42] measurement system, Silbernagel et al. [40] calculated the height, repetitions, work, and limb symmetry index (LSI) of the Heel-Rise Test and the ankle range of motion, and used the Pearson correlation coefficient to evaluate the correlation between the Heel-Rise Test and ankle range of movement, and the Spearman correlation coefficient to assess the relationship among the patient-reported symptoms (ATRS) and the Heel-Rise Test and ankle range of motion. The results showed differences in Heel-Rise height between injured and uninjured sides, where the Heel-Rise height increased in the injured side without differences in other individuals. Regarding the Heel-Rise repetition and work, the results showed the presence of significant differences

between injured and uninjured sides. The results also showed that the normal function and height parameter improved along the time. Finally, the ankle range of motion increased on the injured side without differences in the uninjured side.

The MuscleLab measurement system was also used by the authors of Reference [39] for the calculation of Heel-Rise work, Heel-Rise height, hopping, concentric power, drop countermovement jump (CMJ), and Eccentric power, implementing the Mantel–Haenzsel, Mann–Whitney, and Wilcoxon signed rank test for the evaluation of the differences between the injured and uninjured sides. The results presented significant improvements in ATRS between 6 months and 12 months, and surgical persons presented better results at 6 months. After one year, the level of function of the injured leg was lower than the uninjured leg.

In Reference [38], the authors calculated the ATRS, the repetitions, work, LSI values and height of Heel-Rise Test, the hopping, the drop countermovement jump (CMJ), the concentric power, and the eccentric–concentric power for the evaluation between one and two years after an acute Achilles tendon rupture in patients treated surgically or non-surgically. The descriptive data, including median, standard deviation, mean, maximum, minimum, and range, were calculated, and the Wilcoxon’s signed-rank test was used to evaluate the differences between injured and uninjured patients. Also, the Mann–Whitney U test was used for the comparison of two groups of patients. The comparison of the results obtained between the 12 months and 24 months revealed that the Heel-Rise work, repetitions and height improved in non-surgical patients and reduced in surgical patients. On the contrary, the hopping decreased in non-surgical patients and maintained in surgical patients. Finally, the drop CMJ, the concentric power, and the eccentric–concentric power revealed that the function of non-surgical patients reduced, and the surgical patients showed an improvement.

Bayer et al. [27] also used the MuscleLab measurement system for the examination of tissue perfusion as an indirect marker of inflammation over time, and the relation between tissue perfusion and morphological changes of the muscle. For this purpose, the authors used statistical analysis with muscle volume, muscle isometric strength, muscle isokinetic strength of the thigh muscles, test of calf muscle function, and perception of symptoms and readiness. The study showed that there was an increasing gastrocnemius muscle fatigue even several years after Achilles tendon ruptures, and the muscle fatigue was achieved with a limited number of elevations.

In Reference [28], the authors examined the evolution of the tendon elongation, mechanical properties, and functional outcomes, after a surgery of Achilles tendon ruptures, extracting the plantar flexion strength 0°, plantar flexion strength 12°, range of motion, Heel-Rise index, and Heel-Rise height. For these features, the authors implemented one-way and two-way analysis of variance (ANOVA) and Tukey multiple comparisons, reporting that the patient reported functional scores without normal values at 12 months.

Byrne et al. [29] used the IBM SPSS Statistics 23 for the measurement and comparison of the intrarater test–retest reliability and measurement agreement of the three Heel-Rise Test outcome measures based on the height of each repetition. They calculated the mean and standard deviation for the calculation of standardized mean difference effect size. After that, different measurements were performed including the standard error of measurement, the coefficient of variation, the minimal detectable change at the 90% confidence level, and Pearson’s correlation coefficient, reporting acceptable reliability and agreement that were equivalent to the traditional measurement of the number of repetitions.

The MuscleLab measurement system was also used by the authors of Reference [30] for the evaluation of the ability to perform standardized seated Heel-Rises 3 months after an Achilles tendon rupture and the assessment calf muscle endurance and function. For this purpose, the authors considered the number and height of repetitions, applying the Mann–Whitney U-test, and Wilcoxon’s signed rank test for the analysis of the data. It was verified that the performance of the test is reliable to quantify the progress and to predict future functional performance.

The linear encoder was used by the authors of Reference [37] with the measurement of Heel-Rise height and the number of repetitions, analyzing them with intraclass correlation coefficient, and Wilcoxon signed rank test, and calculating the minimal detectable change. It was verified that significative differences existed between injured and uninjured legs for both tendon length and Heel-Rise height.

The authors of References [33] also measured the height of each repetition with a linear encoder, applying four multiple linear regression models. It was verified that the increasing age reduced significantly the height of each repetition.

Nawoczinski et al. [31] used the Flock of Bird 6 degree of freedom electromagnetic sensor motion capture system for the measurement of determine the effect of an isolated gastrocnemius recession procedure on ankle power and endurance. They measured the limb symmetry index, and they used the SPSS Statistical software with the implementation of Mann–Whitney U and Wilcoxon signed-rank test, verifying reduced scores in ankle endurance.

The electromyography sensors are used in Reference [32] for the evaluation of muscle fatigue with number of repetitions, highest Heel-Rise (mm), and sum work of all Heel-Rises, and the first 10 Heel-Rises. These features were analyzed with SPSS statistical software, implementing the Mann–Whitney U and Wilcoxon signed-rank test, verifying that the subjects increased gastrocnemius muscle fatigue, and it can be detected with a limited number of repetitions.

Neville et al. [34] used capacitive sensors in a shoe for the comparison of the total and distributed loading patterns in subjects with stage II tibialis posterior tendon dysfunction. The variables included in the study are the hindfoot inversion/eversion, the forefoot abduction/adduction, and the medial longitudinal arch (MLA) height. The variables were compared, and the authors implemented a linear regression method, verifying that medial longitudinal height presents a high level of correlation.

In Reference [36], the authors only measured the number of repetitions to apply the one-way analysis of variance and Bonferroni correction. The results showed that the individuals with athletic tape condition decreased the number of repetitions performed, and it is statistically different than other conditions such as placebo tape and non-tape.

Finally, the Power plate pro was used in [35] for the determination of the effects of the treatment. The features extracted from the data were the Electromyography (EMG) amplitude, frequency analysis, and timing of EMG activity, implementing different statistical analysis for processing. Thus, it was verified that whole body vibration (WBV) increases in the soleus muscles during the early phases of Heel-Rise Test.

4. Discussion

Commonly, mobile devices have several sensors embedded that allows the recognition and identification of different types of movement [10,18,43–45]. However, the Heel-Rise Test has a small number of studies available in the literature, and, commonly, the sensors used are not related to the sensors available in the mobile device. Thus, the different studies considered the use of a platform for the identification of the number of repetitions.

In the 1940s, the Heel-Rise Test was developed for the assessment of the calf muscle–tendon unit useful for several disciplines, including cardiology, neurology, orthopedics, gerontology, and sports medicine [24,46]. This test consists of the performance of elevations of the heel under a single leg, providing a reliable evaluation of plantar flexion strength and endurance after lower limb injury or injury to the Achilles tendon [40,47]. Also, the Heel-Rise test helps in the quantification of the treatment outcomes. This test performs different measurements, including calf muscle endurance, fatigue, strength, performance, and function of lower limbs [21,24,25]. The elevations should be controlled, and the individual should perform the exercise without a break until the performance of the task cannot be completed correctly or the verification of a pain or fatigue in calf muscles [46–48]. The average value of heel rises in healthy subjects is 25 elevations, but other numbers have been suggested in the literature [24].

The results showed that the Heel-Rise test has proven in the verification of the recuperation of different diseases. As verified in Table 2, the number and height of repetitions are the most important features to control the evolution of the Heel-Rise Test. Following the methods used, as the primary goal of the Heel-Rise Test is to control the development of the treatment, they are mainly statistical methods. The studies are more concentrated in Europe with its performance based on the use of pressure sensors and the MuscleLab measurement system based on the data acquired by people of different ages.

Table 2. Features available in the different studies.

| Features | Number of Studies | Studies |
|--|-------------------|---------------------|
| Heel-Rise height | 10 | [27–30,32,33,37–40] |
| Heel-Rise repetitions | 7 | [27,30,32,36–38,40] |
| Heel-Rise work | 3 | [38–40] |
| Limb symmetry index (LSI) | 3 | [31,38,40] |
| Ankle range of motion | 2 | [38,40] |
| Concentric power | 1 | [39] |
| Drop countermovement jump (CMJ) | 1 | [39] |
| Eccentric power | 1 | [39] |
| Electromyography (EMG) amplitude | 1 | [35] |
| Forefoot abduction/adduction | 1 | [34] |
| Frequency analysis | 1 | [35] |
| Heel-Rise index | 1 | [28] |
| Hindfoot inversion/eversion | 1 | [34] |
| Hopping | 1 | [39] |
| Mean speed of the centre-of-pressure displacements | 1 | [41] |
| Medial longitudinal arch (MLA) height | 1 | [34] |
| Muscle isokinetic strength of the thigh muscles | 1 | [27] |
| Muscle isometric strength | 1 | [27] |
| Muscle volume | 1 | [27] |
| Plantar flexion strength 0° | 1 | [28] |
| Plantar flexion strength 12° | 1 | [28] |
| Range of motion | 1 | [28] |
| Surface area covered by the trajectory of the center-of-pressure | 1 | [41] |
| Timing of EMG activity | 1 | [35] |
| Weight-bearing index | 1 | [41] |

Finally, there is not available in the literature a validated system for the measurement of the results of the Heel-Rise Test, and the studies available in the literature were found eight years ago. The automation and improvement of the processes to control the evolution of the different treatments are included in the research on ambient assisted living and the development of medical systems. The Heel-Rise Test needs more analysis with commonly used sensors (e.g., mobile devices) for the creation of an expanded solution for the monitoring of health-related to physical therapy.

5. Conclusions

The sensors may handle the more accurate measurement of the results of the Heel-Rise Test to identify the different parameters of this test, where the most common and vital settings consist of the number of repetitions of the exercise. This test may allow the identification of the evolution of the treatment to plantar flexion strength and endurance after lower limb injury or injury to the Achilles tendon. The different sensors available on the market may reduce the instrumentation of people, performing the measurements with a single device.

Only a small set of studies proposed the use of pressure sensors for the measurement of the number of elevations performed during the Heel-Rise Test. Commonly, a healthy adult may perform 25 repetitions, but it may vary with the different diseases. These studies were focused on the use of pressure sensors and other proprietary equipment, but a preliminary study was performed with pattern recognition using a mobile device [21]. These devices and sensors are capable of acquiring

different types of data related to the health of the subject [49]. This review confirms that it is possible to improve the measurement of the results of Heel-Rise Test with sensors, allowing the performance of the test with autonomy.

Four studies that match with this systematic review were analyzed, and the main findings are presented as follows:

- (RQ1) *How to measure the Heel-Rise Test with sensors?* The use of sensors is a great challenge for the measurement of the Heel-Rise Test. We found in the literature that the most commonly used sensors were pressure sensors. Sensors may help in the measurement of the results of Heel-Rise Test, reducing the number of pieces of equipment needed for the analysis of the results. The sensors may help in the different measurements in physical therapy and medicine subjects.
- (RQ2) *Which features extracted from the different sensors may support the analysis of the results of the Heel-Rise Test?* Various features can be obtained from the sensors to measure the results of Heel-Rise Test. These are Heel-Rise repetitions, ankle range of motion, Heel-Rise height, Heel-Rise work, LSI, mean speed of the center-of-pressure displacements, surface area covered by the trajectory of the center-of-pressure, and weight-bearing index.
- (RQ3) *How to improve the measurement of the Heel-Rise Test in the future?* The analysis of the Heel-Rise Test may be enhanced with the use of automated and artificial intelligence methods for the study of the different results of this test in the treatment of various diseases in lower limbs.

We identified a small number of studies related to the implementation of different techniques for the measurement of the Heel-Rise Test with sensors that can support the work of different medical people. The advances in the treatment of various diseases may be improved with this test. This review proves that the use of the sensors may promote the performance of the test with more accuracy using different types of sensors.

The inertial sensors embedded on mobile devices may help in the measurement of the results of the Heel-Rise Test. Previously, we proposed the creation of a personal digital life coach for the diagnostics of physical therapy [50]. The implementation of machine learning methods allows the creation of more accurate methods, and the development of these methods with technological equipment may increase the commodity and people's health.

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