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Smartphone IMU Integration: Precision Boost for Sit-to-Stand Test with the Equilibrium Mobile Application

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ABSTRACT

This study introduces an innovative approach that integrates the Inertial Measurement Unit (IMU) sensor of a smartphone for conducting the 5 Times Sit to Stand Test (5xSST) through the Equilibrium by Vayu Technology (EQ) mobile application. Engaging a sample of 16 participants, the research utilized the EQ mobile application for data acquisition during the 5xSST, in parallel with high-speed video recording of the participants executing the test. The video footage was then rigorously annotated by three independent experts. A comparative analysis of the data from the EQ mobile application and the annotated video revealed a significant level of precision, matching, and/or surpassing benchmarks set in existing research. Additionally, this study incorporates kinematic analysis for the 5 Times Sit to Stand Test (5xSST), providing a comprehensive evaluation of participants' movements.
The Root Mean Square Error (RMSE) of this method stands at 3.26%, notably better than the results of traditional methods. The absolute error for the total duration of the 5xSST was recorded at 0.16 ± 0.1 seconds, which is consistent with the ranges reported in the literature. Additionally, a percentage error of 1.3 ± 0.84% highlights the accuracy and reliability of this smartphone-based approach. This study marks a significant advancement in functional mobility assessments, leveraging mobile technology to achieve greater precision and methodological rigor, thereby contributing a valuable perspective to the domain of health assessments.

Keywords: Inertial Measurement Unit (IMU),5 Times Sit to Stand Test (5xSST), Equilibrium (EQ) mobile application, Kinematic analysis, Functional mobility assessments, Smartphone-based health assessment, Precision and accuracy.

1. INTRODUCTION

1.1 BACKGROUND

The field of physical health assessment is witnessing a continuous evolution, where traditional methods are being seamlessly woven with the fabric of modern technology. At the forefront of this evolution lies the 5 Times Sit-to-Stand (5xSST) test, a cornerstone assessment tool in healthcare [1]. Recognized for its simplicity and effectiveness, the 5xSST evaluates lower limb strength, balance, and overall functional mobility by requiring individuals to transition from sitting to standing five times consecutively, with the speed of completion acting as a key indicator [5]. This test has been widely used in geriatric care, for individuals with chronic mobility limitations, and in rehabilitation settings [4].

However, the landscape of physical assessments is undergoing a significant transformation, driven by the emergence of more sophisticated and readily available technologies. This shift from manual, observational methods towards objective, precise, and quantifiable techniques mark a new era in health and fitness assessments [2]. At the heart of this technological revolution lies the integration of smartphone technology, particularly the utilization of Inertial Measurement Unit (IMU) sensors. Embedded in most modern smartphones, these sensors possess the remarkable ability to capture intricate movement details, offering a wealth of data on acceleration, orientation, and gravitational forces [3].

The convergence of smartphone technology with traditional assessment methods represents not just a step towards modernization, but a significant leap in the accuracy and reliability of health assessments. IMU sensors within smartphones can track and analyze movements in three-dimensional space with unprecedented precision [6]. When applied to the 5xSST, this technology unlocks a new dimension of information, allowing for a detailed analysis of the sit-to-stand motion and capturing nuances that were once beyond the reach of conventional methods.

This integration is reshaping the landscape of health assessments, moving beyond the confines of clinical settings and empowering individuals. It reflects a broader shift in healthcare towards personalized, accessible, and technology-driven practices. As we continue this path of integration and innovation, the potential of such technologies to redefine our understanding and approach to health assessments becomes increasingly evident.

1.2 SIGNIFICANCE

The integration of smartphone technology into the 5xSST presents several significant implications for healthcare, enhancing the precision, simplicity, and accessibility of mobility assessments:

- **Early Detection and Prediction:** The application facilitates early detection of mobility impairments, crucial for timely interventions that can improve patient outcomes and quality of life. Early detection is often indicative of various health conditions, making this technology invaluable in preventive care.
- **Effective Rehabilitation:** By providing precise data, the smartphone application enables healthcare professionals to tailor rehabilitation programs more effectively. This allows for accurate tracking of a patient's progress and the identification of specific areas needing focus, ensuring personalized and efficient care.
- **Increased Accessibility:** The ubiquity of smartphones and their advanced sensors democratize the assessment process. Patients could potentially perform the 5xSST in the comfort of their homes, reducing the need for frequent clinical visits. This accessibility is vital for patients in remote areas or those with mobility issues.
- **Support for Telehealth and Remote Patient Monitoring:** As the trend towards telehealth grows, the application's potential for remote monitoring of patients' mobility becomes increasingly relevant. It assesses the feasibility of integrating such technology into telehealth programs, contributing to more responsive and personalized care. This approach not only aligns with the needs of modern healthcare systems but also ensures continuous patient monitoring, enabling real-time adjustments to treatment plans and fostering a patient-centered care model.

2. LITERATURE REVIEW

Bochicchio et al. (2023) conducted a validation study on the use of a wearable 3D Inertial Sensor to estimate muscle power during the 5 Sit to Stand Test in older individuals. The study compared the sensor-based measures of total trial time, mean concentric time, velocity, force, and muscle power against those obtained from laboratory equipment. With 62 older adults participating, the study found significant correlations between the two methods for all measured variables, suggesting the potential of the wearable sensor as a practical alternative to traditional laboratory methods for assessing muscle power in older adults. The research provides valuable insights into the use of technology in clinical assessments and could lead to more accessible and efficient methods for monitoring and diagnosing conditions related to muscle power in the elderly [7].

Agbohessou et al. (2023) conducted a study evaluating the validity and reliability of a custom wrist-worn inertial measurement unit (IMU) in assessing physical fitness tests, specifically, the Sit to Stand (STS) and Timed Up and Go (TUG) tests. The study involved two groups - young healthy adults and adults with chronic diseases. Results indicated a significant correlation between the custom device's measurements and the traditional methods, confirming its potential utility in remote monitoring and assessment of physical fitness, especially in chronic disease management. The study's findings highlight the effectiveness of wearable technology in health monitoring, offering insights for future research in physical fitness assessment using advanced technologies [8].

Jung et al. (2021) conducted a study assessing the correlation between human interpretation (5STShuman) and a rule-based algorithm (5STSrule) using instrumented 5STS with two sensors. The study involved 148 geriatric outpatients and analyzed their performance in the five times sit-to-stand test (5STS), a critical measure for evaluating lower extremity physical performance and diagnosing sarcopenia. The study found a strong correlation between 5STShuman and 5STSrule, indicating that the rule-based algorithm is effective in classifying sarcopenia, with comparable classification ability to human interpretation. This research provides valuable insights into the use of instrumented 5STS in clinical assessments of physical performance and sarcopenia in older adults [9].

Fudickar et al. (2020) conducted a comprehensive study on the Unsupervised Screening System (USS) for assessing physical performance in older adults, focusing on the Timed "Up & Go" (TUG) and Five Times Sit-to-Stand (SST) tests. This system incorporated both ambient and wearable sensors to autonomously measure performance. The study, involving 91 participants aged between 73 to 89, compared the USS's sensor data against traditional stopwatch measurements. The results show significant correlations for both TUG (0.89 for light barriers, 0.78 for inertial sensors) and SST (0.73 for light barriers, 0.87 for inertial sensors) tests, validating the USS as a reliable tool for unsupervised physical performance assessment in older adults. The study's findings hold substantial implications for proactive health monitoring and intervention in aging populations, offering a new avenue for assessing physical abilities without the need for constant supervision [10].

3. RESEARCH GAP

While the field of functional mobility assessment has witnessed significant advancements, particularly with the integration of technology, there remains room for improvement in the literature, which this research aims to fill. Existing studies exploring the use of smartphone technology, and specifically the Inertial Measurement Unit (IMU) sensors, for conducting the 5 Times Sit to Stand (5xSST) test have established a basic understanding. Yet, these investigations often fall short of offering a detailed phase breakdown analysis, namely, the Sit to Stand and Stand to Sit phases, which are critical for a comprehensive assessment of functional mobility.

One notable gap is the limited exploration into the precision and reliability of smartphone technology in capturing detailed kinematic data during the 5xSST test. This study aims to quantitatively analyze and compare the kinematic data obtained from smartphones, specifically looking at the distinct phases of the 5xSST, with traditional assessment techniques to offer a more nuanced understanding of their effectiveness.

Furthermore, the literature often overlooks the practicality of utilizing smartphone technology in daily health assessments, focusing instead on the technical capabilities of these devices. This research intends to bridge this gap by not only examining the technical precision of the EQ mobile application in conducting the 5xSST test but also its user experience and accessibility. We are particularly interested in how the EQ mobile application can enhance the standard assessment by providing detailed kinematic data of the trunk, enabling practitioners to track the bend angle during both standing and sitting down phases with unprecedented accuracy and ease. A detailed description of the EQ mobile application’s flow for the 5xSST test is provided in section 5.3.

Moreover, existing research has often been narrow in scope, focusing on small or specific patient groups. This study will broaden this perspective by including a diverse cohort of subjects to validate the EQ mobile application's applicability and reliability across a wider range of individuals. This inclusive approach will provide more generalizable findings and contribute to a comprehensive understanding of smartphone technology's role in health assessments.

By addressing these gaps, this research not only enriches the existing body of knowledge but also introduces innovative, accurate, and patient-friendly methodologies in the realm of physical health assessments, marking a significant step forward in the integration of technology in healthcare.

4. RESEARCH OBJECTIVES

The overarching aim of this research is to enhance the precision and effectiveness of the 5 Times Sit to Stand (5xSST) test measurements through the utilization of a dedicated smartphone application. In pursuit of this goal, the study is structured around several key objectives:

- **To Validate the precision of EQ mobile application in a 5xSST test:** The primary objective is to quantitatively assess the accuracy of the 5xSST test measurements obtained using the smartphone application. This involves comparing the data collected through the Smartphone’s Inertial Measurement Unit (IMU) sensors against data annotated by 3 video annotators.
- **To Encourage the Use of Kinematic Data:** A crucial objective is to advocate for the inclusion of kinematic data, such as trunk forward bend angles, in the assessment of standing up and sitting down movements. Understanding these kinematic parameters has significant clinical relevance in analyzing the biomechanics of these actions. Incorporating this data can provide deeper insights into the physical health and functional abilities of patients, thereby enhancing the diagnostic and rehabilitative processes in clinical settings.
- **To Highlight User Accessibility and Experience:** An essential aspect of this research is to evaluate the user-friendliness of the smartphone application. This includes assessing the ease with which users can navigate the application, conducting the 5xSST test, and interpreting the results. Understanding the user experience is crucial in ensuring that the application is accessible and practical for a broad spectrum of users, including patients, healthcare professionals, and caregivers.

By accomplishing these objectives, the research endeavors to make a significant contribution to the field of physical health assessments, enhancing the accuracy, accessibility, and practicality of the 5xSST test through innovative smartphone technology.

5. EXPERIMENTAL SETUP

5.1 SELECTION OF PARTICIPANTS

The study involved a diverse group of 16 participants, carefully selected to encompass a range of demographics including variations in age, gender, and fitness levels. Participants were aged 20 to 72 years, ensuring a wide representation of the adult population. This age range was chosen to ensure that the findings of the study would be applicable and relevant to a broad spectrum of the population, from young adults to older individuals. The inclusion of individuals with varied backgrounds and physical abilities was crucial for assessing the generalizability and effectiveness of the smartphone application across different user groups.

5.2 DESIGN OF THE EXPERIMENT

The experiment was meticulously designed to evaluate the precision and usability of the EQ mobile application in conducting the 5 Times Sit to Stand (5xSST) test. Each participant was instructed to perform the 5xSST using a standard height chair, ensuring uniformity in the test conditions. The application was installed on smartphones to ensure compatibility and robustness across different platforms. The experimental setup also included a high-definition video recording of each subject performing the test at 120 frames per second (fps) using a smartphone, providing a side-view perspective for accurate movement analysis.

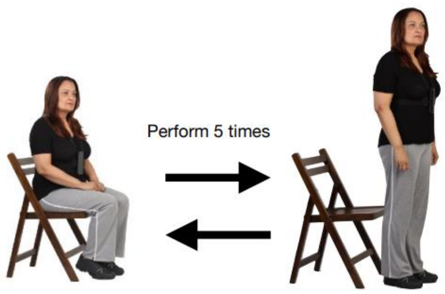

Figure 1: Setup of 5xSST test with a smartphone strapped to user's chest.

5.3 EQ APP FLOW FOR 5xSST TEST

The EQ mobile application's interface for the 5xSST (Five Times Sit-to-Stand) Test is meticulously designed to enhance user engagement and comprehension through a structured pre-test and post-test flow. This section elucidates the sequential framework and content organization within the application, as depicted in Figures 2 and 3, corresponding to the pre-test and post-test flows, respectively.

5.3.1 PRE-TEST FLOW

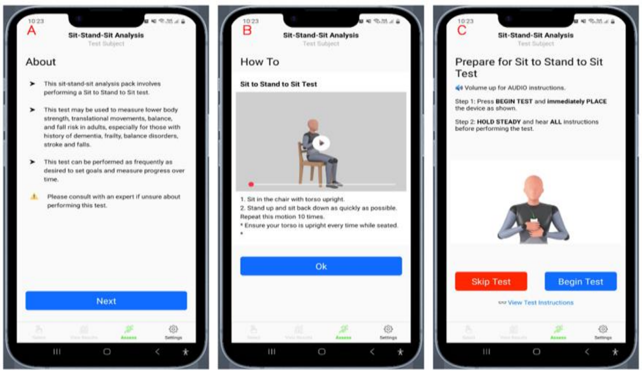

Figure 2: EQ mobile application pre-test flow for 5xSST test.

The pre-test flow is segmented into three distinct sections (Figure 2A-C), each tailored to prepare the user adequately for the 5xSST test:

- **Figure 2A (Introduction):** This initial segment serves an educative purpose, presenting comprehensive information about the 5xSST test, including its significance, methodology, and potential applications. It aims to familiarize users with the test's objectives and the relevance of its outcomes.
- **Figure 2B (Instructional Guide):** Termed the "how to" section, it meticulously outlines the procedural steps for conducting the 5xSST test. It includes detailed setup instructions, a step-by-step guide with haptic feedback and voice instructions for performing the test accurately, and an integrated audio-video demonstration to ensure clarity and correct execution.
- **Figure 2C (Test Preparation):** The final segment before initiating the test, this section instructs users on the correct placement of the phone to ensure precise data capture. A prominent "begin test" option is provided, signaling the start of the test and the user's interactive engagement with the application.

5.3.2 POST-TEST FLOW

The post-test flow is divided into three sections (Figure 3A-C), each designed to offer detailed feedback and personalized recommendations based on the test results:

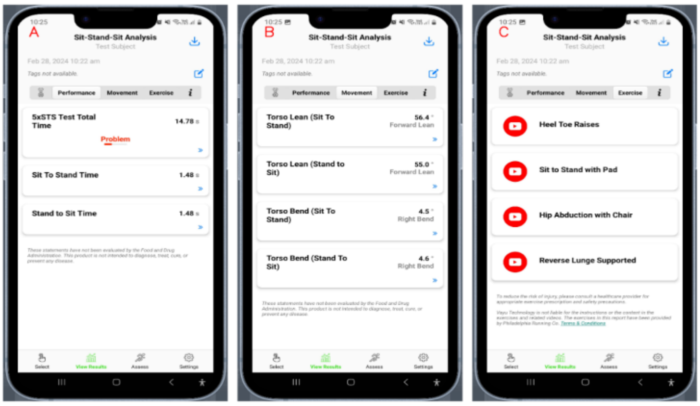

Figure 3: EQ mobile application post-test flow for 5xSST test.

- **Figure 3A (Performance Analysis):** This section displays the test's temporal statistics, including the total duration, individual sit-to-stand, and stand-to-sit times. It also assigns a performance rating based on the total time, offering users a quantifiable assessment of their physical functionality.
- **Figure 3B (Movement Statistics):** Providing a deeper dive into the physical dynamics of the test, this segment presents metrics such as average torso lean and bend, captured during the test's sit-to-stand and stand-to-sit phases. This data is crucial for understanding the user's movement patterns and potential areas for improvement.
- **Figure 3C (Personalized Exercise Recommendations):** Tailored exercises are suggested in this final section, derived from the user's test performance. These recommendations aim to support individuals in enhancing their functional mobility, thereby potentially improving future 5xSST test outcomes.

The EQ mobile application's design for the 5xSST test showcases a user-centric approach, emphasizing ease of understanding and interaction. The logical progression from introductory information through detailed instructions to personalized feedback ensures a comprehensive and engaging user experience. This design not only facilitates accurate test execution but also empowers users with insightful feedback, fostering motivation for ongoing health and fitness improvement. The integration of instructional visuals and result-oriented graphics further enhances the utility and user-friendliness of the application, making it an effective tool for individuals seeking to monitor and enhance their physical well-being.

5.4 DATA COLLECTION METHODS

The data collection process was rigorously structured to capture detailed and accurate information. This included documenting the frequency and duration of each 5xSST test performed by the participants. Calibration procedures were implemented to ensure that the smartphone application accurately recorded the movements. The high-speed video recording at 120 fps was critical in capturing the detailed nuances of each sit-to-stand transition, allowing for a comprehensive analysis of the movements. Figure 4 represents segmentation of phases in 5xSST test by EQ mobile application which is developed from the learnings of high fidelity data from EQ pro system (motion capture system by Vayu Technology) and ML models to learn and supercharge smartphones.

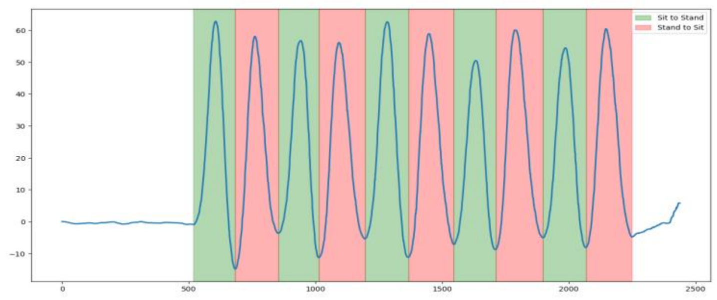

Figure 4: 5xSST test phase segmentation using orientation data of the trunk segment.

5.5 TOOLS AND TECHNOLOGIES USED

The primary tool used in this study was the EQ mobile application, which was utilized to record and analyze the 5xSST test results. For video recording, a smartphone was used, set to record at 120 fps to ensure high-quality footage of each participant's performance. To align the video data closely with the EQ mobile application data, which is collected at 100Hz, the 120 fps video was later down-sampled to 100 fps. This adjustment ensured that the video data could be directly matched with the EQ mobile application data, facilitating precise synchronization.

The recorded video data were meticulously annotated by three trained annotators. These annotators were provided with the down-sampled videos, which were synchronized with the EQ mobile application data (also sampled at 100Hz), to capture different points of interest such as the start of standing, end of standing, start of sitting, and end of sitting for each of the 5 sit to stands. This process was critical for accurately identifying the key moments of each test, allowing for a detailed comparison between the EQ mobile application data and the observed movements in the video.

The overall 5xSST times captured by the EQ mobile application were compared with the video annotations, both in percentage format and absolute time in seconds. Furthermore, a comprehensive statistical analysis, including R^2 analysis and confidence intervals at the 95% level, was conducted to compare the results obtained from the EQ mobile application with those from the video annotations. This multi-faceted approach ensured a thorough evaluation of the EQ mobile application's accuracy in measuring the 5xSST test, highlighting the importance of precise data collection and analysis techniques in validating the effectiveness of digital health tools.

6 RESULTS

6.1 DATA ANALYSIS AND FINDINGS

In this section, we present a detailed statistical analysis of the temporal parameters obtained from the 5xSST (5 times Sit-to-Stand Test) through EQ mobile application, compared against high-speed video data. The analysis includes the coefficient of determination (R^2), confidence interval analysis, and absolute error in both seconds and percentages. These metrics are consolidated in Table 1.

Paper	**ERROR (%)**	**ERROR (s)**	**RMSE %**	**Phase Comparison vs Video in R^2**	**Phase Comparison vs Video in CI 95%**
EQ RESULTS	1.3 +/- 0.84 %	0.16 +/- 0.1	3.26%	Total 5xSST = 0.99 Sit to Stand = 0.87 Stand to Sit = 0.90	(avg error, max error) Total 5xSST = (0.2, 0.39) Sit to Stand = (0.07, 0.22) Stand to Sit = (0.10, 0.29)

Table 1: Statistical Analysis of Temporal Parameters in 5xSST Test.

Rigorous comparison between application-derived data and high-speed video recordings has unearthed significant insights into the application's precision and reliability. To facilitate a straightforward and intuitive comprehension of these insights, we've employed graphical representations, which are encapsulated in Figures 5 and 6.

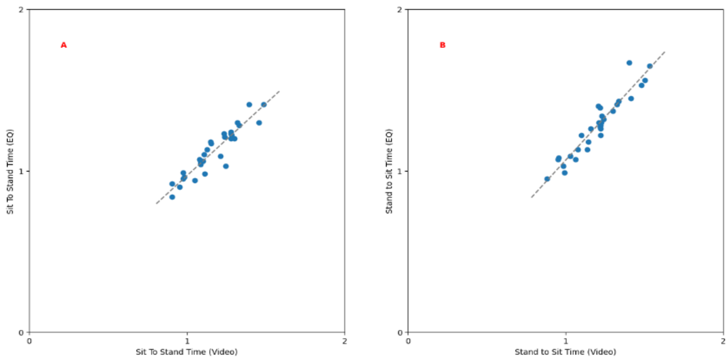

Figure 5: Video vs EQ mobile application representation of Sit to Stand Time and Stand to Sit Time in 5xSST Test

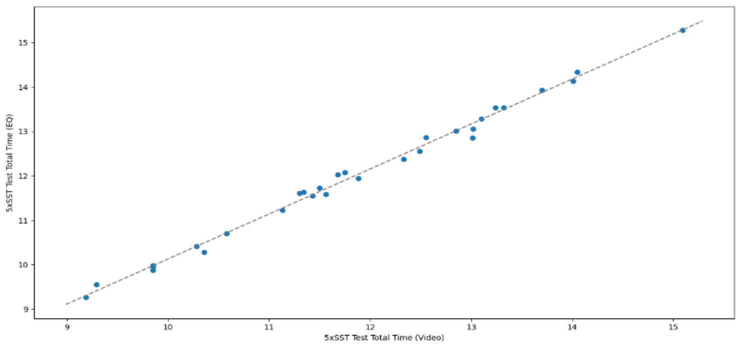

Figure 6: Video vs EQ mobile application representation of Total 5xSST Test time.

These visual aids are instrumental in conveying the nuanced differences and the overall accuracy and consistency of the application in capturing the temporal parameters of the 5xSST Test, thereby affirming its viability as a reliable tool for clinical and research purposes.

6.2 KINEMATIC PARAMETERS ANALYSIS IN 5xSST TEST

The kinematic analysis of the 5xSST Test is presented in this section, detailing the torso movements during the Sit-to-Stand and Stand-to-Sit transitions. "Table 2: Torso Movements in 5xSST Test" captures the average and standard deviation of these movements, expressed in degrees, highlighting the range and consistency of motion among participants.

	Absolute Average (in degrees)	Absolute Standard Deviation (in degrees)
Torso Lean (Sit To Stand)	24.91	14.38
Torso Lean (Stand to Sit)	30.04	12.69
Torso Bend (Sit To Stand)	4.12	2.29
Torso Bend (Stand To Sit)	4.45	2.44

Table 2: Torso Movements in 5xSST Test

The data indicates that participants exhibited moderate variability in the degree of torso lean (sagittal movement) when moving from sitting to standing, with an average lean of 24.91 degrees. The transition from standing to sitting showed a slightly greater average torso lean (sagittal movement) of 30.04 degrees but displayed more consistency across trials, as suggested by the lower standard deviation.

In terms of torso bending (frontal movement in both sides), the movements were relatively minor, with average angles of 4.12 degrees and 4.45 degrees for Sit-to-Stand and Stand-to-Sit transitions, respectively. Both transitions demonstrated a consistent bending pattern among participants, as reflected by the small standard deviations.

These findings underscore the application's capability to reliably capture the kinematic details of torso movement during the 5xSST Test.

6.3 COMPARISON WITH EXISTING SIT-TO-STAND ASSESSMENT METHODS

This section provides a comparative analysis of the results obtained from the 5xSST (5 times Sit-to-Stand Test) using the EQ mobile application against established benchmarks in the literature. The comparison is twofold, encompassing both statistical outcomes and test setups utilized in various studies.

Paper	Error (%)	Error (s)	RMSE %	Phase Comparison vs Video in R^2
EQ RESULTS	1.3 +/- 0.84 %	0.16 +/- 0.1	3.26%	Total 5xSST = 0.99 Sit to Stand = 0.87 Stand to Sit = 0.90
[8]	--	--	7.22%	Total 5xSST = 0.96
[7]	1.20%	0.12		Total 5xSST = 0.99
[9]		0.7		Total 5xSST = 0.98
[11]		0.52		Total 5xSST = 0.99
[10]				Total 5xSST using USS = 0.73 Total 5xSST using IMU = 0.87

Table 3: Comparison of Temporal Parameters in 5xSST Test

Table 3 presents a side-by-side evaluation of the temporal parameters derived from the EQ mobile application with those reported in existing research. This comparison emphasizes the degree of correlation (R^2), confidence interval analysis, and absolute error (both in seconds and as a percentage), offering a direct juxtaposition with the findings documented in the literature.

Paper	No. of Subjects	No. of Trials	System Used	Sensor/Phone placement	Comparison
EQ RESULTS	16	28	Smart-Phone	Trunk	Video-Annotated by 3 people
[8]	31 Young		IMU	Wrist Worn	
[7]	62	62	IMU	Right Thigh	FP and Mo-cap
[9]	126		Lidar	*on Chair*	Human interpreting signal
[11]	458 Old		IMU	Trunk	Stopwatch
[10]	91 Old		IMU and USS		

Table 4: Comparison of Test Setup for 5xSST Test

Further to the statistical comparison, **Table 4** examines the methodologies applied in different studies. This includes an assessment of the tools and techniques used, the environmental setup, participant demographics, and any specific protocols that were followed. The aim is to illustrate the robustness of the EQ mobile application's test setup concerning the diverse approaches observed in the field.

Through these comparisons, we aim to establish the validity and reliability of EQ mobile application for the 5xSST Test, while also highlighting areas of improvement and future research opportunities.

7. DISCUSSION

7.1 INTERPRETATION OF FINDINGS

The results of this study indicate that the 5 Times Sit to Stand (5xSST) test results obtained from the EQ mobile application demonstrate a marked improvement over those reported in the existing literature. This finding suggests that the application not only enhances the precision of the 5xSST test but also may offer a more reliable tool for clinical assessments. In interpreting these findings, it is important to consider the role of advanced sensor technology in smartphones and how it contributes to the increased accuracy of physical assessments. The integration of this technology into routine clinical practices can potentially transform the standard approach to functional mobility assessments, making them more precise and efficient.

7.2 IMPLICATIONS FOR HEALTHCARE AND TECHNOLOGY

The implications of this study extend beyond the realm of technological advancement and into practical applications within healthcare. The enhanced accuracy and reliability of the 5xSST test using the EQ mobile application could lead to improved early detection of mobility issues, more tailored rehabilitation programs, and better monitoring of patient progress. This has significant implications for patient care, particularly in geriatrics, physical therapy, and rehabilitation medicine. Furthermore, the study highlights the potential of smartphone technology in healthcare, opening up possibilities for more accessible and user-friendly health monitoring tools. It underscores the importance of continuing to develop and integrate technology in healthcare to improve patient outcomes and healthcare efficiency.

8. CONCLUSION

8.1 SUMMARY OF KEY FINDINGS

This research has highlighted the significant capabilities of smartphone Inertial Measurement Unit (IMU) sensors in conducting basic fitness assessments, specifically through the 5 Times Sit to Stand (5xSST) test. The study's key finding is that the EQ mobile application in performing the 5xSST test not only aligns with traditional methods but, in many cases, surpasses them in terms of accuracy and reliability. This advancement is a testament to the potential of integrating modern technology into traditional healthcare practices, offering a more precise and efficient approach to functional mobility assessments.

8.2 POTENTIAL IMPACT ON HEALTH ASSESSMENT PRACTICES

The implications of these findings are far-reaching, particularly in the domains of healthcare and fitness assessment. By utilizing the advanced capabilities of smartphone sensors, there is a significant opportunity to enhance the precision of physical assessments, leading to better diagnosis, monitoring, and treatment of mobility-related issues. This technology could be particularly beneficial in geriatric care, rehabilitation, and for individuals with chronic conditions affecting mobility. The use of such technology can potentially streamline the assessment process, making it more accessible and less time-consuming for both healthcare providers and patients.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This study's promising results necessitate further research in several key areas. Future studies should aim to identify and mitigate potential sources of error in data collection, ensuring greater accuracy and reliability. Additionally, it is essential to test the application in diverse real-world settings to validate its practicality and effectiveness beyond controlled environments. Lastly, ongoing development and refinement of the technology are crucial, to keeping pace with the rapid advancements in smartphone capabilities and evolving healthcare needs. Addressing these areas will significantly enhance the application's efficacy and applicability in healthcare.

Declaration by Authors
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