THE VALIDITY, RELIABILITY, AND SENSITIVITY OF A SMARTPHONE-BASED SEATED POSTURAL CONTROL ASSESSMENT IN WHEELCHAIR USERS

BY

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THESIS

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ABSTRACT

Seated postural control is essential for wheelchair users to maintain proper position while performing activities of daily living. Clinical tests are commonly used to measure seated postural control in wheelchair users, yet they are subjective and lack sensitivity. Lab-based measures are highly sensitive but are limited in scope and restricted to research settings. Establishing a valid, reliable and accessible measurement tool of seated postural control is necessary to better understand and remotely track seated postural control. Therefore, the purpose of this study was to examine the validity, reliability, and sensitivity of smartphone-based postural control assessments in wheelchair users. Eleven participants (age: 35.4 $\pm$ 17.9) completed two experimental visits 1-week apart consisting of three clinical tests: Trunk Control Test (TCT), Function in Sitting Test (FIST), and Tee-Shirt Test, as well as, standardized instrumented balance tasks that manipulated vision (eyes open and closed), and trunk movement (functional reach and stability boundary). During these balance tasks, participants held a smartphone and research-grade accelerometer to their chest. Maximum and root mean square (RMS) acceleration in the medial-lateral (ML) and anterior-posterior (AP) axes were derived. Participants were grouped into non-impaired and impaired postural groups based on FIST scores. Spearman rank-order correlations between the two devices' outcome measurements were conducted, and receiver operating characteristic (ROC) and the area under the curves (AUC) were determined to distinguish participants with and without impaired postural control. The reliability of outcome variables was assessed using inter-class correlations. Strong correlations between outputs derived from the smartphone and research-grade accelerometer were seen across balance tasks (ρ=-0.75–1.00; $p \leq 0.01$). The AUC for ROC plots were significant for RMS ML sway during the eyes open task and functional stability boundary (p=0.05 and 0.02, respectively). Reliability of smartphone accelerometry was comparable to the research-grade accelerometer and clinical tests. This pilot study illustrated that smartphone technology may be able to provide a valid and reliable assessment of seated postural control and have the ability to distinguish between those with and without impaired postural control. Leveraging this form of technology could allow for remote, accessible and objective seated postural control assessments for wheelchair users.

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CHAPTER 1: BACKGROUND

It is currently estimated that there are ~65 million wheelchair users worldwide[1]. Of these, ~3.3 million reside in the United States of America, where researchers are expecting annual growth of new users due to the exponential growth of older adults[2]. Wheelchair users face numerous challenges to maintaining an active and engaged life, which can be exacerbated by impaired seated postural control. Seated postural control is the ability to maintain one's center of mass within stability boundaries while in a seated position, and is comprised of a complex interplay of sensory processing and motor outputs[3,4]. Alterations to sensory or motor processing can result in a decline in seated postural control[5], and jeopardize an individual's ability to safely perform activities of daily living[6]. As such, improving seated postural control is a common goal of rehabilitation interventions[7]. Consequently, objectively measuring seated postural control in wheelchair users is necessary to guide prevention and rehabilitative strategies.

There are numerous ways to measure seated postural control. Researchers have developed several clinical measures including, but not limited to, the Function in Sitting Test[8–10], Trunk Control Test[11], and the Tee-shirt Test[12] to assess seated postural control. These clinical measures have few technological requirements but require clinical expertise to perform. There are also concerns that these measures are subjective and lack sensitivity[13]. Researchers have also utilized three-dimensional motion capture techniques[14,15], video-based measurements[16], posturography[5,15], and accelerometry[17] to assess seated postural control. These research lab-based measures are objective and sensitive to impairment but require relatively expensive technology, expertise, and consequently are potentially limited in scope. Establishing an objective valid and reliable measurement tool to understand and monitor seated postural control is warranted[6].

A possible avenue for achieving objective accessible measures of seated postural control is through the utilization of mobile technology. Indeed, researchers have leveraged mobile health technology, specifically smartphone and tablet embedded sensors, to assess standing postural control[18,19]. Recent work has shown that mobile technology is a valid[20,21] and reliable[21,22] tool to provide objective assessments of standing balance, have a high level of usability[23] and are sensitive to impairment[20]. Although promising, it is not clear if smartphone-based accelerometry can provide a valid and reliable assessment of seated postural control in wheelchair users. Therefore, the purpose of the current pilot study is to determine the validity, reliability, and sensitivity of smartphone-based seated postural control assessments in adult wheelchair users, as an initial step in the remote monitoring of seated postural control. Based on previous research, we hypothesized that smartphone-based accelerometry can provide a valid and reliable measure of seated postural control and have the ability to distinguish between those with and without impaired postural control.

CHAPTER 2: MATERIALS AND METHODOLOGY

2.1 Participants

Eleven non-ambulatory adults (age: 35.4 ± 17.9; gender: 4 males, 7 females) were recruited from the local community to participate in the current study *(see Table 2.1)*. To be eligible, individuals were required to be ≥18 years old, utilize a wheeled mobility device for their main form of mobility, manual dexterity sufficient to swipe on a smartphone, normal or corrected to normal hearing and vision, and able to read and speak English. Individuals were excluded from the study if they were unable to meet these criteria or if they were unable to sit upright for at least 1-hour. The University of Illinois at Urbana-Champaign Institutional Review Board approved all procedures, and all participants provided written informed consent before engaging in research activities.

2.2 Research protocol and data analyses

Participants completed two identical experimental sessions, one week apart. The first experimental session began by obtaining written informed consent and participant demographic information. At each session, participants completed three clinical tests that have been shown to provide a valid measure of seated posture control: the Function in Sitting Test (FIST)[10], Trunk Control Test (TCT)[11], and T-shirt Test[12]. Following these tests, participants completed a series of unsupported seated balance tasks while holding a smartphone (Samsung Galaxy S6, Samsung, Seoul, South Korea) that was equipped with a research-grade accelerometer (APDM Wearable Technologies, Portland, OR) *(see Figure 2.1)*.

Four seated balance tasks were completed in a standardized order that increased in difficulty: static sitting with eyes open (EO), static sitting with eyes closed (EC), functional reach (FR), and functional stability boundary (FSB). These tests were chosen because of their ability to provide insight into those with and without impaired postural control[5].

All tests except for the functional reach task were completed for 30 seconds. The functional reach task was not constrained by time. Two trials of each task were completed. During testing, participants held the smartphone with their dominant hand against their sternum and in standardized orientation *(see Figure 2.1)*. The smartphone was sampled at an average rate of 200 Hz and the research-grade accelerometer was collected at 128 Hz.

A custom MATLAB script (MathWorks Inc., Natick, MA) aligned and downsampled all accelerometry data to 100 Hz. Maximum (MAX) and root mean squared (RMS) acceleration time-series from each device along the anterior-posterior (AP) and medial-lateral (ML) axes, as well as the 95% confidence ellipse area (CEA), were calculated. These measures are seen to be a valid assessment of postural stability[24] and sensitive enough to identify impairment in other populations[20,24,25].

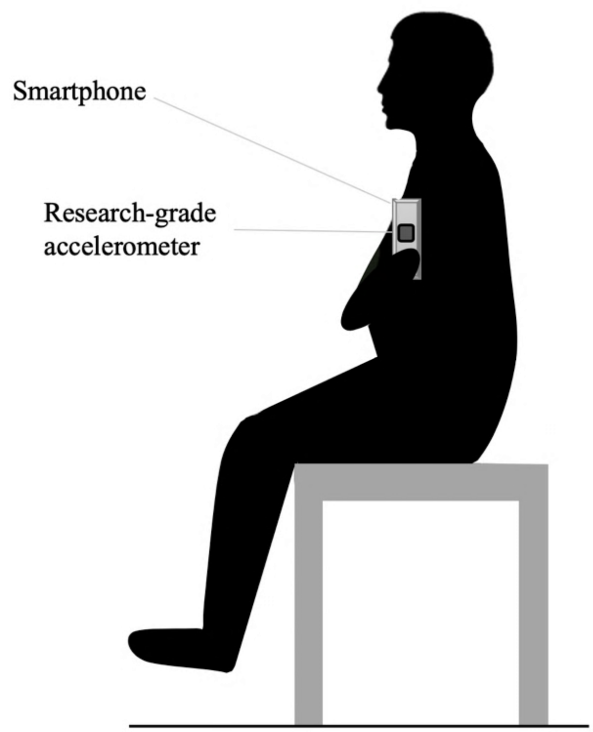

Figure 2.1. Illustration of a participant completing the seated postural control assessment.

2.3 Statistical analysis

IBM Statistical Package for the Social Sciences (SPSS) for Windows, version 26 (IBM Corp, Armonk, NY) was used to complete all statistical analyses with statistical significance set at $\alpha = 0.05$. All values are reported as mean $\pm$ standard deviation unless otherwise noted.

Extreme outliers, as defined as, any data values which lie more than 3.0 times the interquartile range were removed from the data set. Within the first and second sessions, extreme outliers made up 0.97% and 1.29% of the data, respectively. Once outliers were removed, the two trials of each balance task (EO, EC, FR, FSB) from a given session were averaged together. To assess the validity of the smartphone, Spearman rank-order correlations between the smartphone and research-grade accelerometer were measured for all balance conditions. Correlation coefficients of 0.1 were considered small, 0.3 were considered moderate, and 0.5 were considered large[26]. The reliability of the smartphone, research-grade accelerometer, and clinical tests were measured by conducting interclass correlations (ICC) of their respective outcome variables from session 1 and session 2.

A median split of FIST scores was used to separate participants into two groups: those with and without impaired seated postural control. Once separated, independent sample T-tests were performed to identify potential differences in age and clinical test outcome measures during all balance conditions. To further understand the difference between the two groups, the effect sizes (Cohen's *d*) were calculated. Effect sizes were classified as small (*d*= 0.20), medium (*d*=0.50), and large (*d*=0.80)[27]. To determine the smartphone's sensitivity, receiving operating characteristic (ROC) curves were constructed and the area under the curve (AUC) was calculated for RMS ML, RMS AP, and CEA to determine the classification accuracy of those with and without impaired seated postural control.

Table 2.1. Participant demographic information. Values are reported as mean ± standard deviation. * indicates that $p<0.05$.

	Participants With Impaired Postural Stability	**Participants Without Impaired Postural Stability**	**Levene's Test for Equality of Variances**	**Independent Samples Test *(2-tailed)***	**95% CI**	**Cohen's *d***
Sample Size	n=5	n=6	-	-	-	-
Age (years)	27.8 ± 10.9	41.7 ± 21.0	0.141	0.217	[-9.78, 37.5]	-0.947
Gender	Males: 2, Females:3	Males: 2, Females: 4	-	-	-	-
Reason for wheeled-mobility	SCI: 3, Sacral Agenesis: 1, diastematomyella: 1	SCI: 2, MS: 3, CP: 1	-	-	-	-
FIST	41.4 ± 6.0	53.2 ± 2.4	0.031*	0.009*	[4.42, 19.1]	-2.585
TCT	17.2 ± 3.0	21.2 ± 1.7	0.064	0.023*	[0.686, 7.25]	-1.575
Tee-shirt Test (sec)	20.8 ± 7.6	25.3 ± 20.9	0.073	0.659	[-17.9, 27.0]	-0.404
Functional reach (cm)	10.6 ± 4.9	18.6 ± 11.1	0.042*	0.157	[-3.92, 19.9]	-1.114
Lateral reach (cm)	4.8 ± 3.1	10.7 ±7.0	0.357	0.116	[-1.78, 13.5]	-1.274

CHAPTER 3: RESULTS

Results from the research grade accelerometer indicated that maximum ML acceleration ranged from -6.92 m/s^2 to 5.47 m/s^2 and had mean value of -0.68$\pm$2.16 m/s^2, and maximum AP acceleration ranged from 0.68 m/s^2 to 8.66 m/s^2 and had mean value of 5.37$\pm$2.09 m/s^2. RMS ML acceleration ranged from 0.22 m/s^2 to 3.98 m/s^2 and had mean value of 1.16$\pm$0.86 m/s^2, and RMS AP acceleration ranged from 0.25 m/s^2 to 7.47 m/s^2 and had mean value of 4.13$\pm$1.87 m/s^2.

As for the smartphone, maximum ML acceleration ranged from -0.99 m/s^2 to 6.71 m/s^2 and had mean value of 1.79$\pm$1.64 m/s^2, and maximum AP acceleration ranged from -8.28 m/s^2 to 7.50 m/s^2 and had mean value of 2.11$\pm$3.13 m/s^2. RMS ML acceleration ranged from 0.158 m/s^2 to 4.16 m/s^2 and had mean value of 1.18$\pm$0.877 m/s^2, and RMS AP acceleration ranged from 0.39 m/s^2 to 7.73 m/s^2 and had mean value of 4.31$\pm$1.90 m/s^2.

3.1 Validity

Spearman rank-order correlations between the smartphone and research-grade accelerometer outcome variables revealed numerous significant relations. Maximum acceleration along the ML (EO and EC) ($p \leq 0.01$) and AP (EO, EC, and FR) ($p \leq 0.01$) axes were significantly correlated between devices *(see Table 3.1)*. Measures of RMS acceleration and CEA yielded strong, significant correlations between the two devices ($p \leq 0.011$), except for ML acceleration during the eyes closed balance task (p=0.124) *(see Table 3.1)*.

Table 3.1. Presents the correlations (Rho) of maximum (MAX) and root mean square (rms) acceleration as derived through smartphone and research-grade accelerometry. ** indicates a significant correlation where p<0.01 level (2-tailed). * represents that p<0.05.

Balance Task	Accelerometry Variable	Rho (*ρ*)	*p*-value
Eyes Open	MAX ML	-0.755	0.007*
	MAX AP	0.982	<0.01**
	RMS ML	0.918	<0.01**
	RMS AP	1.000	<0.01**
	CEA	0.727	0.011*
Eyes Closed	MAX ML	0.866	0.01**
	MAX AP	0.864	0.01**
	RMS ML	0.492	0.124
	RMS AP	0.936	<0.01**
	CEA	0.909	<0.01**
Functional Reach	MAX ML	0.515	0.128
	MAX AP	0.818	0.004*
	RMS ML	0.964	<0.01**
	RMS AP	0.945	<0.01**
	CEA	0.982	<0.01**
Functional Stability Boundary	MAX ML	0.218	0.519
	MAX AP	0.527	0.096
	RMS ML	0.991	<0.01**
	RMS AP	1.000	<0.01**
	CEA	0.891	<0.01**

3.2 Reliability

Reliability was seen across all clinical measurements ($p \leq 0.005$), except the TCT ($p=0.077$) *(see Table 3.2)*. As for accelerometry, 55% of the smartphone and 60% of research-grade accelerometer outcome variables were found to be reliable *(see Table 3.3 & Table 3.4)*. The smartphone was the most reliable across outcome variables during the EC balance test, while the research-grade accelerometer was the most reliable across outcome variables during the functional stability boundary test *(see Table 3.3 & Table 3.4)*.

Table 3.2. Interclass correlations (ICC) between clinical test outcomes during session 1 and session 2. Function in sitting test: FIST, Trunk Control Test: TCT. ** indicates a significant correlation where p<0.01.

Clinical Test	95% CI (single)	ICC (single)	95% CI (mean)	ICC (mean)
FIST	[0.296, 0.924]	0.745 (*p*=0.003)**	[0.457, 0.961]	0.854 (*p*=0.003)**
TCT	[-0.185, 0.810]	0.438 (*p*=0.077)	[-0.454, 0.895]	0.609 (*p*=0.077)
Tee-shirt Test	[0.346, 0.932]	0.769 (*p*=0.002)**	[0.514, 0.965]	0.869 (*p*=0.002)**
Forward Reach	[0.234, 0.914]	0.714 (*p*=0.005)**	[0.379, 0.955]	0.833 (*p*=0.005)**
Lateral Reach	[0.404, 0.940]	0.795 (*p*=0.001)**	[0.575, 0.969]	0.886 (*p*=0.001)**

Table 3.3. Interclass correlations (ICC) between maximum (MAX) acceleration, root mean squared (RMS) acceleration, and confidence ellipse area (CEA) as recorded through smartphone accelerometry during session 1 and session 2. ** indicates a significant correlation where p<0.01 while * represents p<0.05.

Balance Tasks	Accelerometry Variable	95% CI (single)	ICC (single)	95% CI (mean)	ICC (mean)
Eyes Open	MAX ML	[-0.378, 0.723]	0.253(*p*=0.214)	[-1.217, 0.839]	0.403 (*p*=0.214)
	MAX AP	[-0.168, 0.815]	0.451 (*p*=0.070)	[-0.405, 0.898]	0.622 (*p*=0.070)
	RMS ML	[-0.208, 0.801]	0.418 (*p*=0.088)	[-5.24, 0.890]	0.590 (*p*=0.088)
	RMS AP	[0.885, 0.991]	0.968 (*p*<0.01)**	[0.939, 0.996]	0.984 (*p*<0.01)**
	CEA	[-0.593, 0.558]	-0.026 (*p*=0.532)	[-2.917, 0.716]	-0.054 (*p*=0.532)
Eyes Closed	MAX ML	[-0.005, 0.864]	0.572 (*p*=0.026)*	[-0.011, 0.927]	0.728 (*p*=0.026)*
	MAX AP	[-0.029, 0.877]	0.583 (*p*=0.030)*	[-0.060, 0.935]	0.737 (*p*=0.030)*
	RMS ML	[0.170, 0.902]	0.679 (*p*=0.008)*	[0.291, 0.949]	0.809 (*p*=0.008)*
	RMS AP	[0.947, 0.996]	0.986 (*p*<0.01)**	[0.973, 0.998]	0.993 (*p*<0.01)**
	CEA	[-0.638. 0.507]	-0.098 (*p*=0.619)	[-3.520, 0.673]	-0.216 (*p*=0.619)
Functional Reach	MAX ML	[0.311, 0.927]	0.752 (*p*=0.002)*	[0.474, 0.962]	0.859 (*p*=0.002) *
	MAX AP	[-0.419, 7.38]	0.244 (*p*=0.234)	[-1.445, 0.849]	0.393 (*p*=0.234)
	RMS ML	[0.734, 0.978]	0.921 (*p*<0.01)**	[0.847, 0.989]	0.959 (*p*<0.01)**
	RMS AP	[0.659, 0.971]	0.895 (*p*<0.01)**	[0.795, 0.985]	0.945 (*p*<0.01)**
	CEA	[-0.576, 0.576]	0.000 (*p*=0.500)	[-2.717, 0.731]	0.000 (*p*=0.500)
Functional Stability Boundary	MAX ML	[0.123, 0.893]	0.653 (*p*=0.011)*	[0.220, 0.944]	0.790 (*p*=0.011)*
	MAX AP	[-0.288, 0.769]	0.346 (*p*=0.136)	[-0.808, 0.869]	0.514 (*p*=0.136)
	RMS ML	[0.747, 0.979]	0.925 (*p*<0.01)**	[0.855, 0.990]	0.961 (*p*<0.01)**
	RMS AP	[0.765, 0.981]	0.931 (*p*<0.01)**	[0.867, 0.990]	0.964 (*p*<0.01)**
	CEA	[-0.249, 0.785]	0.382 (*p*=0.110)	[-0.661, 0.880]	0.553 (*p*=0.110)

Table 3.4. Interclass correlations (ICC) between maximum (MAX) acceleration, root mean squared (RMS) acceleration, and confidence ellipse area (CEA) as recorded through research-grade accelerometry during session 1 and session 2. ** indicates a significant correlation where p<0.01 while * represents p<0.05.

Balance Tasks	Accelerometry Variable	95% CI (single)	ICC (single)	95% CI (mean)	ICC (mean)
Eyes Open	MAX ML	[-0.572, 0.580]	0.006 (*p*=0.493)	[-2.675, 0.734]	0.011 (*p*=0.493)
	MAX AP	[0.860, 0.989]	0.960 (*p*<0.001)**	[0.925, 0.995]	0.980 (*p*<0.001)**
	RMS ML	[0.074, 0.899]	0.647 (*p*=0.016)	[0.138, 0.947]	0.786 (*p*=0.016)
	RMS AP	[0.891, 0.992]	0.969 (*p*<0.01)**	[0.942, 0.996]	0.984 (*p*<0.01)**
	CEA	[-0.609, 0.541]	-0.050 (*p*=0.562)	[-3.111, 0.702]	-0.106 (*p*=0.562)
Eyes Closed	MAX ML	[0.127, 0.894]	0.655 (*p*=0.010)**	[0.226, 0.944]	0.792 (*p*=0.010)**
	MAX AP	[0.762, 0.981]	0.930 (*p*<0.01)**	[0.865, 0.990]	0.964 (*p*<0.01)**
	RMS ML	[0.074, 0.899]	0.647 (*p*=0.016)	[0.138, 0.947]	0.786 (*p*=0.016)
	RMS AP	[0.891, 0.992]	0.969 (*p*<0.01)**	[0.942, 0.996]	0.984 (*p*<0.01)**
	CEA	[-0.576, 0.576]	0.000 (*p*=0.500)	[-2.717, 0.731]	0.000 (*p*=0.500)
Functional Reach	MAX ML	[-0.608, 0.596]	-0.009 (*p*=0.511)	[-3.102, 0.747]	-0.019 (*p*=0.511)
	MAX AP	[0.520, 0.955]	0.844 (*p*<0.01)**	[0.685, 0.977]	0.915 (*p*<0.01)**
	RMS ML	[0.658, 0.971]	0.895 (*p*<0.01)**	[0.793, 0.985]	0.944 (*p*<0.01)**
	RMS AP	[0.616, 0.966]	0.880 (*p*<0.01)**	[0.762, 0.983]	0.936 (*p*<0.01)**
	CEA	[-0.576, 0.576]	0.000 (*p*=0.500)	[-2.717, 0.731]	0.000 (*p*=0.500)
Functional Stability Boundary	MAX ML	[0.352, 0.933]	0.772 (*p*=0.002)*	[0.521, 0.965]	0.871 (*p*=0.002)*
	MAX AP	[0.288, 0.923]	0.741 (*p*=0.003)*	[0.448, 0.960]	0.851 (*p*=0.003)**
	RMS ML	[0.744, 0.979]	0.924 (*p*<0.01)**	[0.853, 0.989]	0.960 (*p*<0.01)**
	RMS AP	[0.780, 0.982]	0.936 (*p*<0.01)**	[0.876, 0.991]	0.967 (*p*<0.01)**
	CEA	[-0.502, 0.641]	0.104 (*p*=0.374)	[-2.018, 0.782]	0.188 (*p*=0.374)

3.3 Sensitivity

To determine sensitivity, the eleven participants were separated into two groups, those with (n=5) and without (n=6) impaired seated postural control *(see Table 2.1)*. Per design, group differences were observed in the FIST (p=0.009) as well as the TCT performance (p=0.023). The effect sizes ranged from small to large (d: -0.40 to -2.59).

To distinguish individuals with and without impaired seated postural control, ROC curves were constructed, and AUC was calculated for RMS ML, RMS AP, and CEA *(see Table 3.5)*. The AUC for RMS ML ranged from 0.433±0.188 to 0.933±0.078, RMS AP ranged from 0.500±0.186 to 0.667±0.174, and CEA ranged from 0.467±0.209 to 0.800±0.144 (values are mean±SE). The AUC was statistically significant for RMS ML sway during the EO (p=0.045) and FSB (p=0.018) balance tasks *(see Table 3.5 and Figure 3.1)*.

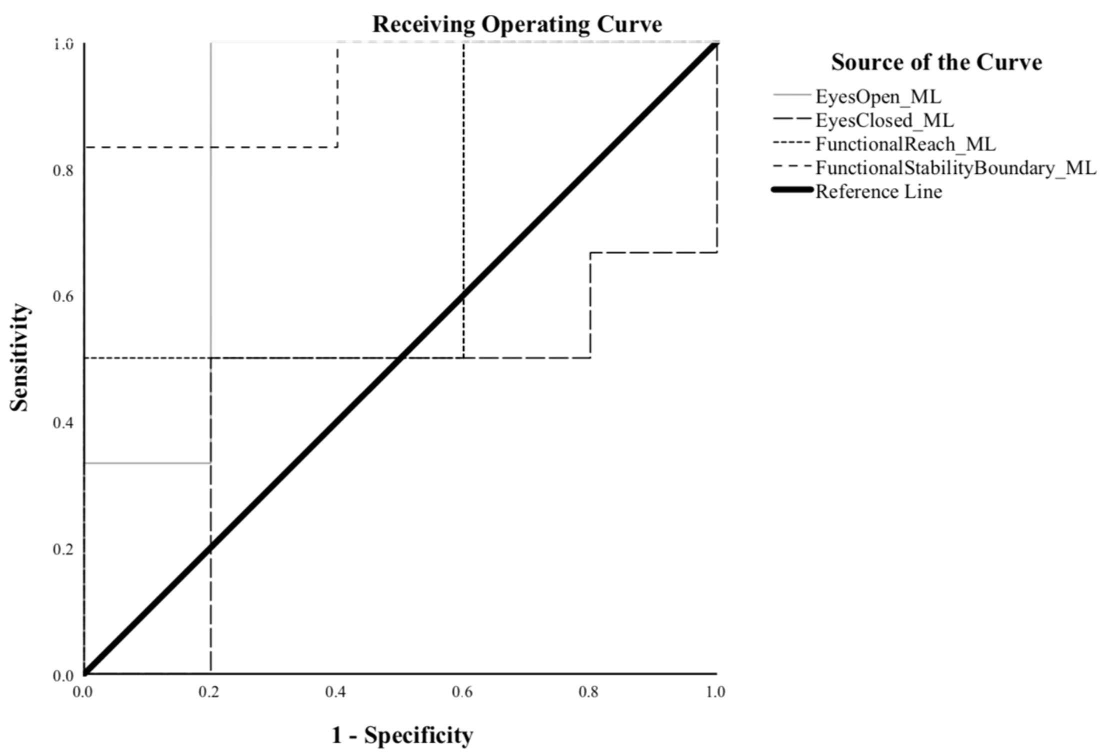

Figure 3.1. Receiving operating curves for root mean squared smartphone acceleration in the medial-lateral (ML) direction during all balance tasks

Table 3.5. Receiving operating curve statistical outcomes. AUC: area under the curve, SE: Standard error. * indicates p<0.05.

Balance Task	Smartphone Measurements	AUC (SE)	*p*-value	95% Confidence Interval
Eyes Open	RMS ML	0.867 (0.130)	0.045*	[0.612, 1.000]
	RMS AP	0.600 (0.181)	0.584	[0.245, 0.955]
	CEA	0.500 (0.207)	1.000	[0.094, 0.906]
Eyes Closed	RMS ML	0.433 (0.188)	0.715	[0.065, 0.801]
	RMS AP	0.667 (0.174)	0.361	[0.325, 1.000]
	CEA	0.467 (0.209)	0.855	[0.094, 0.906]
Functional Reach	RMS ML	0.700 (1.70)	0.273	[0.366, 1.000]
	RMS AP	0.533 (0.189)	0.855	[0.164, 0.903]
	CEA	0.500 (0.187)	1.000	[0.133, 0.867]
Functional Stability Boundary	RMS ML	0.933 (0.078)	0.018*	[0.780, 1.000]
	RMS AP	0.500 (0.186)	1.000	[0.134, 0.866]
	CEA	0.800 (0.144)	0.100	[0.518, 1.000]

CHAPTER 4: DISCUSSION

Understanding the validity, reliability, and sensitivity of smartphone-based seated postural control during various balance tasks is critical in the efforts of providing wheelchair users with an objective and accessible tool to measure seated postural control. Within the current study, smartphone-based measures of seated postural control were found to be valid, have reliability that was on par or greater than the clinical tests, and capable of discriminating between individuals with and without impaired seated postural control. Collectively, the observations provide preliminary evidence that smartphone-based accelerometry is suitable for objectively measuring seated postural control in adult wheelchair users.

Due to the strong significant correlations between outputs derived from the smartphone and research-grade accelerometer, the current investigation indicates that the smartphone provides a valid measure of seated postural control. This is in line with recent studies which illustrated that smartphone accelerometry provided a valid measure of standing postural stability when compared against research-grade equipment[20,21].

Quantifying seated postural control has been a topic of scientific interest, utilizing a wide array of technology (e.g. three-dimensional motion capture, video-based measures, and force plate measures)[5,14–16]. Accelerometry has been used to evaluate the movement of transfers in adult wheelchair users[28], yet limited work has utilized this technology to quantify seated postural control, resulting in limited recommendations concerning how to best quantify the acceleration signal. Research focusing on standing balance has recommended the use of RMS as the "best" measure[20,24,29]. Consistent with these recommendations, the current investigation found strong correlations between smartphone and research-grade accelerometry when RMS quantified the signal. Collectively this supports the notion that RMS of acceleration is a valid measure of seated postural control and should be incorporated into future study designs investigating accelerometry-based seated postural control.

Along with identifying the validity of accelerometry-based movement and balance tasks, past investigations have shown this form of technology to be reliable as well[21,22,29–31]. In agreeance with this literature, findings from the current study provide evidence that the smartphone RMS acceleration is as reliable as that of a research-grade accelerometer. Of the 12 possible RMS outcomes variables, RMS derived from smartphone accelerometry yielded 7 significant inter-class correlations (ICC) while the research-grade accelerometer yielded 6.

Clinical tests, particularly the FIST and TCT, have been reported as reliable measures of seated postural control in clinical populations[10,11]. The current results confirm the reliability of the FIST, Tee-shirt Test, Forward Reach, and Lateral Reach. The level of reliability of smartphone-based accelerometry was on par with or greater than those of the clinical tests. Such observations further support the notion that smartphone technology is a reliable and objective measurement of seated postural control for wheelchair users.

In order to provide meaningful results, smartphone technology must have the sensitivity to differentiate between those with varying degrees of postural control. In the past, smartphone accelerometry has been able to do discriminate between standing postural control in frailty (frail/non-frail)[25] and fall risk (low/high)[20] within older adults. Within the current study, the easiest (EO) and most challenging (FSB) tasks were able to identify participants with and without impaired postural control, specifically in the ML direction. Recent work also supports this observation by providing evidence that those with impaired seated postural control exhibit greater decrements in their lateral (ML) reach than forward (AP) reach[10]. These collective findings indicate that smartphone technology may have the sensitivity to identify those with and without impaired seated postural control and that postural instability within wheelchair users may be rooted in mediolateral instability.

CHAPTER 5: CONCLUSION

To better understand seated postural control, and monitor changes over time, we must establish an objective and sensitive measurement tool. To our knowledge, this is the first investigation examining the validity, reliability, and sensitivity of smartphone-based accelerometry as a tool to quantify seated postural control in adult wheelchair users. Results from this study illustrated that smartphone technology may be able to provide a valid and reliable assessment of seated postural control and have the ability to distinguish between those with and without impaired postural control – especially in the ML plane. Given the ubiquitous nature of smartphones in society, there is great potential for mobile technology to provide quick, easily accessible, and objective remote monitoring of seated postural control in adult wheelchair users.

CHAPTER 6: LIMITATIONS AND FUTURE DIRECTIONS

Limitations of the current study include limited sample size, albeit with a diverse range of seated postural control, and the use of a single smartphone and research-grade accelerometer. Future research should incorporate a larger sample to further investigate the reliability of accelerometry based seated postural control assessments and the feasibility of leveraging this form of technology in place of commonly performed clinical tests. Along with this, researchers need to develop a health application interface to provide this type of assessment and determine its usability, validity, and reliability of results, responsiveness to interventions (i.e. sensitivity to changes in seated balance), and home use acceptance.

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