Comparing Usability and Variance of Low- and High Technology Approaches to Gait Analysis in Health Adults

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COMPARING USABILITY AND VARIANCE OF LOW- AND HIGH
TECHNOLOGY APPROACHES TO GAIT ANALYSIS
IN HEALTHY ADULTS

By
John McConnell
Brian Silverman

A doctoral project submitted in partial fulfillment
of the requirements for the

Doctorate of Physical Therapy

Department of Physical Therapy
School of Allied Health Sciences
The Graduate College

University of Nevada Las Vegas
May 2015
We recommend the doctoral project prepared under our supervision by

John McConnell and Brian Silverman

entitled

Comparing Usability and Variance of Low- and High Technology Approaches to Gait Analysis in Health Adults

is approved in partial fulfillment of the requirements for the degree of

Doctor of Physical Therapy

Department of Physical Therapy

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ABSTRACT

Purpose: The purpose of this study was to compare the usability, reliability, and objectivity of four tools that represented varying gait analysis technologies used in clinical practice and/or research. Low technology clinical tools included the Gait Abnormality Rating Scale (GARS-M) and the Rancho Los Amigos Observational Gait Analysis (Rancho OGA). High technology tools included the GAITRite® computerized walkway, and the APDM Mobility Lab™ wearable sensor system.

Subjects: 74 healthy adults ages 18-41 years (mean = 24.82, SD = 4.39) 33 males and 40 females.

Methods: Subjects were instructed to walk at a self-selected speed for two minutes during which clinical and spatiotemporal gait characteristics were measured concurrently using the four tools.

Results: A qualitative analysis was created to display usability characteristics for each tool. GARS-M and Rancho OGA yielded fair to moderate Inter-rater reliability scores (K=0.41, K=0.31) and moderate Intra-rater reliability scores (ICC3,2=0.65, ICC3,2 = 0.64, ICC3,2=0.48, ICC3,2=0.53). Comparison analysis of GARS-M and Rancho OGA resulted in a high specificity (Sp=0.96) and high positive likelihood ratio(+LR=13.6). No significant difference was found between the seven gait variables measured by GAITRite® and Mobility Lab™ however Pearson correlation analysis showed significant correlations between three of seven measured gait variables: cadence(p<0.001), gait cycle time(p=<0.001), and double limb support % of cycle(p=0.026).

Conclusion: This study showed the GARS-M and Rancho OGA may be useful for clinical gait analysis but objective data are not comparable to the high technology tools. The GAITRite® offers desirable objective data for research but usability factors and high cost may deter its use in the clinic. Mobility Lab™ may be the most suitable for both clinical and research use as it offers objective data.
combined with established clinical measures and more favorable usability factors compared to GAITRite®.
ACKNOWLEDGMENTS

We would like to thank the University of Nevada, Las Vegas Lambda Kappa Delta Pre-Physical Therapy club, and the University of Nevada, Las Vegas Physical Therapy classes of 2015 and 2016 for their cooperation and participation with our participant recruitment in this study. We would also like to thank the UNLV Biomechanics department for their help with data collection as well as their allowance for use of equipment during the data collection process. Lastly, we would like to give a very special thanks to Janet Dufek, Ph.D, FACSM from Kinesiology and Nutrition Sciences, Brendan Morris, Ph.D from Electrical and Computer Engineering and Szu-Ping Lee, PT, Ph.D from Physical Therapy for their mentorship and assistance in study design throughout the research process.
# TABLE OF CONTENTS

ABSTRACT .................................................................................................................. iii
ACKNOWLEDGEMENTS ............................................................................................... v
LIST OF TABLES ........................................................................................................... vii
LIST OF FIGURES ......................................................................................................... viii
INTRODUCTION ........................................................................................................... 1
METHODS ..................................................................................................................... 5
ANALYSIS ...................................................................................................................... 10
RESULTS ...................................................................................................................... 11
DISCUSSION ................................................................................................................ 13
LIMITATIONS .............................................................................................................. 16
CONCLUSION ............................................................................................................ 16
APPENDIX-A ............................................................................................................. 18
APPENDIX-B ............................................................................................................ 22
APPENDIX-C ............................................................................................................. 28
APPENDIX-D ............................................................................................................. 30
REFERENCES ............................................................................................................. 31
CIRRICULUM VITAE ................................................................................................. 33
LIST OF TABLES

**Table 1.** Participant Demographics……………………………………………………..18

**Table 2.** Qualitative Comparisons Across 4 Gait Tools ……………………..19

**Table 3.** Intra-rater and Inter-rater Reliability..............................................20

**Table 4.** GARS-M and Rancho OGA Contingency Table…………………..21

**Table 5.** Results from GAITRite® and Mobility Lab™..............................21
LIST OF FIGURES

Figure 1. APDM Mobility Lab™ and GAITRite® Systems………………..22

Figure 2. Research Flow Chart………………………………………………23

Figures 3-9. Pearson Correlation Coefficients Between Mobility Lab™
and GAITRite®………………………………………………………………………24 - 27
INTRODUCTION

The loss of walking is a common and costly problem that can have a devastating impact on the way individuals participate in the world around them and engage in whole body activities in differing environments. Further, loss of the ability to walk can influence health, wellness, morbidity and mortality. For this reason, walking is classified as a major life activity under the Americans with Disabilities Act.¹ In the United States alone, 30.6 million people over the age of 15 experience difficulty with ambulation activities involving the lower extremities and 7.0 million people aged 65 and over use an assistive device such as a cane, crutches or walker to aid in their ambulation.² Over 17 million adults in the United States ages 18 and over, have significant difficulty or are completely unable to walk at least one quarter mile.³ In addition, an approximate 580,000 children ages 6-14 in the U.S. have difficulty walking or running.² It is estimated that each year $300 million is spent on healthcare to treat physical disabilities that involve walking through direct and indirect costs.⁴

In addition to financial and productivity costs, losing the ability to walk may also lead to a lifestyle of inactivity and therefore have a negative impact on one’s health by affecting multiple body structures and functions which may include bone health, cardiovascular health, and even psychological health.⁵, ⁶ A recent study done by Lee et al,⁷ reported that physical inactivity causes an estimated six to 10% of non-communicable diseases worldwide including coronary artery disease, type II diabetes, breast cancer and colon cancer and also contributes to 9% of premature mortality. Additionally, loss of walking diminishes protective effects of physical exercise seen in the general population and a variety of
patient populations including individuals with stroke and Parkinson’s disease. One basic tenet of patient-centered care is that rehabilitation goals should be mutually agreed upon by providers and patients, and patients very frequently identify a return to walking or improvement of walking as a high priority when asked about their goals for physical therapy episodes of care. For physical therapists and others rehabilitation providers, understanding the cause of the problem is critical to being able to successfully address it and achieve the desired outcomes.

A myriad of tools that focus on or include gait analysis are available across every level of the International Classification of Functioning, Disability, and Health (ICF).\textsuperscript{8} At the level of participation, tools such as the Six-minute walk and the 10 meter walk test focus on whether an individual has adequate walking skills to take part in a variety of roles at home and in the community.\textsuperscript{9} At the level of activity, tools such as the Dynamic Gait Index and the Functional Gait Assessment examine how well a person is able to walk at the level of the whole individual’s function. At the level of body structure and function, tools such as strength or range of motion testing analyze specific factors that may contribute to gait deviations or issues with functional mobility. Clinical gait analysis tools, such as the Rancho Los Amigos Observational Gait Assessment\textsuperscript{10} (Rancho OGA) and the Modified Gait Abnormality Rating Scale\textsuperscript{11} (GARS-M) are widely used and reflect only two of the many different tools used in clinical gait analysis. In fact, the \textit{Guide to Physical Therapist Practice}\textsuperscript{12} identifies 20 different observational tests and measures for the purpose of analyzing gait, all of which can be
obtained for minimal to no cost. The rise of evidence-based practice, increased accountability of rehabilitation professionals to effectively address gait outcomes of their patients, and the dramatic increase in the quality and quantity of rehabilitation research have contributed to technological advancements in gait analysis tools designed to improve precision and repeatability of measurements of varying aspects of gait.

Quantitative data collected from motion analysis equipment can offer a wealth of information about human kinematics, kinetics, joint movements, and spatio-temporal gait variables such as cadence, average stride length, and walking speed. However, the time, space, expense, and training involved in the use of fixed motion capture systems presently put them out of reach for practical clinical use, creating a gap between quantifiable data analysis gathered for research purposes in the laboratory and the tools presently used in clinical practice.

Advancements in portable technologies may create a bridge that is practical for clinical gait analysis outside of the controlled laboratory, and precise enough for use in research. Gregory et al. demonstrated the use of portable accelerometers as a means to measure movement or accelerations of body segments during movement with the capability of approximating the body’s center of mass with less than 5% error. Other wearable technologies including those that incorporate accelerometers with gyroscopes such as the Mobility Lab system™ are considered to be a viable and lower cost alternative to fixed motion
capture with potential for precision\textsuperscript{14} that may exceed some observational methods.

Other devices use computerized pressure detection methods to examine patterns of pressures exerted by each foot as it contacts the support surface and moves through the gait cycle. Pressure-sensitive insoles that can be worn inside the individual’s shoes are one method of applying this technology\textsuperscript{15}, while computerized mats such as the GAITRite® mat and Protokinetics walkways incorporate pressure detection as the individual moves over a path of pressure sensors.

With the vast number and types of tools available, clinicians and researchers must review and weigh the psychometric properties of the possible tools they are considering for use in gait analysis, and the purposes for which they are examining an individual’s gait whether or not they incorporate technology into the analysis. When researchers and clinicians do not use the same measurement tools, the ability of clinicians to apply research-based evidence in their clinical practice is dampened, slowing the process of translating scientific discoveries into clinical reality.\textsuperscript{16}

The purpose of this study was to compare and contrast a selection of commonly used observational gait analysis tools with two types of portable gait assessment technologies in an effort to aid clinicians and researchers in their decision making processes. The specific aims of the study were: (1) to complete a qualitative analysis of usability factors of each of the four tools; (2) to examine intra-rater and inter-rater reliability of the observational tools; (3) to examine
variability between the portable technology tools; and (4) to examine the ability of each of the observational tools compared to each other and to the computerized walkway to detect gait deviations where they existed in our sample.

METHODS

Design

For the purpose of this study we used a cross sectional study design in order to compare and contrast data obtained from multiple systems in the same individuals at a single point in time. Video recordings of these same trials were collected for replay in order to test and support reliability and adherence to the protocol. The study was approved by and conducted under supervision of the Institutional Review Board of the University of Nevada Las Vegas\(^1\).

Subjects

A sample of convenience (n=74) was recruited by email, flyer, and word of mouth on the campus of the University of Nevada, Las Vegas. The sample included healthy adults aged 18 to 41 years (mean = 24.82, SD = 4.39) who were able to ambulate at least 50 feet independently; and had no known neuromuscular condition or active orthopedic injury to the lower extremity. Enrollees who did not meet inclusion criteria or were past the second trimester of pregnancy were excluded from participation. Participants for whom the Ambulatory Parkinson's Disease Monitoring (APDM) Mobility Lab\(^{TM}\) system failed to collect data (n=5) were excluded from the analyses involving Mobility Lab\(^{TM}\).

\(^1\) BM 1311-4638
Instrumentation

The tools used in the study were chosen because they represented a range of tools and technologies currently used in clinical practice or research of which gait analysis is a part. The GARS-M and Rancho OGA are commonly used in clinical practice and do not require equipment beyond a scoring sheet. The GAITRite® and APDM Mobility Lab™ represented gait analysis tools that utilize different types of technology to collect information on spatiotemporal gait characteristics across a variety of healthy and patient populations.

GAIT ABNORMALITY RATING SCALE – Modified (GARS-M)

The GARS-M(Appendix C) is an observational gait analysis tool that is often used in a clinical setting to quickly identify atypical patterns of gait. The GARS-M does not require any equipment other than a copy of the scoring sheet and a writing implement, thus was considered a low technology tool for purposes of this study.

The GARS-M has long been used in clinical settings and has been shown to have a sensitivity of 62.3% and a specificity of 87.1% for identifying gait deviations. This tool scores seven components of gait on an ordinal four-point scale (0-3), with a higher score representing greater gait abnormality. Subjects were observed by two researchers (BS and JM) in both the frontal and sagittal planes while walking at a self-selected gait velocity and were scored on each of the seven items by both researchers.
RANCHO LOS AMIGOS Observational Gait Analysis (Rancho OGA)

The Rancho OGA (Appendix D) is one of the most commonly cited observational assessment tools in literature and was developed by the staff at Rancho Los Amigos Hospital in California in order to quickly identify gait abnormalities without the use of an instrumented gait assessment tool.\textsuperscript{20} Observations are recorded on a form with boxes for the examiner to place a tick mark if an abnormality is identified. The examiner looks at movement in the trunk, pelvis, hip, knee and ankle/foot during different segments of the stance and swing phases of gait and marks the form where they identify an abnormality. The RanchoGait app© is also available for use on a phone or tablet which is free to download but has various in-app purchases available depending on the functionality and usability that the examiner desires. The app was not used in this study, but rather a pen and paper method was used instead.

APDM Mobility Lab™

The Mobility Lab™ is an example of a recently developed moderate to high technology motion analysis system. This motion capture system uses six wireless sensors attached with Velcro straps to various parts of the participants’ body in order to provide a three dimensional evaluation of movement in space. The body locations to which the sensors were attached the left and right wrists, left and right legs, chest and waist; the standard application as directed in the APDM user manual (Figure 1). The chest sensor was placed over the sternum of each participant just below the manubrium. The waist sensor was placed on the
lower back between the two posterior superior iliac spines. Each sensor contains an accelerometer, a gyroscope and a magnetometer to determine orientation and movement of the sensor and the body part to which it is attached. The sensors upload the collected information from each trial to the Mobility Lab™ software where the data can then be interpreted. The Two-Minute Walk protocol and settings were selected in the Mobility Lab™ software during the collection of data in this study.

GAITRite®

GAITRite® is an example of high technology, two-dimensional gait analysis used in research and in other settings.²¹,²²,²³ The GAITRite® mat used for this study measures 12 feet in length and contains pressure sensors to detect foot placement and pressure during ambulation (Figure 2). The mat was laid within a 20-foot walkway to allow turning space on either end of the mat. Subjects were instructed to walk across the mat with each pass.

Procedure

Subjects were recruited from the University of Nevada, Las Vegas (UNLV) through word of mouth. All subjects gave their informed consent and had their questions answered prior to data collection. All subjects were then screened for eligibility and demographic and related information was collected on a brief questionnaire. All data were collected in the in the Paul McDermott Physical
Education Complex (MPE) on the campus of UNLV for screening and data collection sessions.

Testing was performed by two Doctor of Physical Therapy (DPT) students and one biomechanics masters student trained in operating the GAITRite®. Subjects were instructed to walk at a comfortable self-selected pace for two continuous minutes back and forth across the GAITRite® mat without stopping while wearing the Mobility Lab™ sensors. Subjects walked across a flat 20-foot pathway. When the subject reached the end of the designated pathway they turned around and returned along the same path. This was continued for the full two minutes of gait evaluation during which time gait was simultaneously analyzed with all four gait analysis tools and subjects were filmed from the frontal and sagittal plane with two standard video cameras. Data were collected concurrently with each high-tech gait analysis tool for the full two-minutes. Subjects were filmed by two video cameras from frontal and sagittal planes. A large running timer was utilized throughout the gait analysis testing for video recording accuracy when viewing trials at a later time. GARS-M and Rancho OGA were performed by the two DPT students simultaneously for each subject during the two-minute walking trial. Both DPT students received exposure and training on implementing the GARS-M and Rancho OGA through the UNLV DPT program.
Analysis

Usability was analyzed using a qualitative analysis across the 4 tools. Intra-rater reliability was assessed using the Kappa statistic for each of the examiners for each clinical tool (GARS-M and Rancho OGA). Inter-rater reliability of the clinical tools was assessed using the Intraclass Correlation Coefficient Model 2 (ICC2). The strength of association between the two clinical tools by each examiner was evaluated using the Spearman’s rank correlation statistic. The Chi-square statistic was examined for each clinical tool to evaluate the level of agreement between the data collected. Diagnostic accuracy for comparing the ability of the two clinical tools to identify gait deviations was tested using a 2x2 contingency table to examine: sensitivity, specificity, +/- likelihood ratio, +/- predictive value, number needed to treat, and diagnostic odds.

Relationships between values for specific gait parameters: stride length(m), cadence(steps/min), cycle time(sec), stride velocity(m/s), double support%, swing% of cycle, and stance% of cycle as measured using GAITRite® and Mobility Lab™ were examined as follows. Variability between the specific gait parameters was evaluated using paired sample t-test analyses. The agreement between the specific gait parameters was evaluated using the Pearson Correlation Coefficient statistic (PCC). All were set to α=0.05. All quantitative analyses were carried out using IBM SPSS Statistics 20.0 (IFM In, Armonk, New York).
Results

Qualitative analyses of the four gait tools showed no set up time required for both GARS-M and Rancho OGA with an approximate 10 min set up time for both the GAITRite® and Mobility Lab™. Equipment required for both GARS-M and Rancho OGA includes a writing utensil and a physical copy of their respective form. Currently there is an option for a mobile device app for Rancho OGA. Both the GAITRite® and Mobility Lab™ require specific equipment and the use of a computer to run their respective software. There is no training required to use the GARS-M however a clinically trained eye will be usefully in determining the presence of deviations listed within the GARS-M. Training required to use the Rancho OGA at a minimum requires an expert understanding of the Rancho Los Amigos phases of gait. Both the GAITRite® and Mobility Lab™ include tutorials to assist the user in orienting themselves with software and equipment. Space requirements for both GARS-M, Rancho OGA, and Mobility Lab™ only require the minimum desired walking distance set by the examiner. GAITRite® space requirements are constricted to the length of the mat. See Table 2 for side by side comparison between all 4 tools.

Tests for inter-rater reliability revealed a moderate Kappa score between Rater 1 and Rater 2 for GARS-M(K=0.41) and a fair Kappa score between Rater 1 and Rater 2 for Rancho OGA(K=0.31).²⁴

Tests for intra-rater reliability revealed a moderate degree of correlation between Rater 1 live vs video rescore of GARS-M(ICC₃,₂=0.65) and Rancho
OGA (ICC$_{3,2} = 0.64$) and a moderate degree of correlation between Rater 2 live vs video rescore of GARS-M (ICC$_{3,2} = 0.48$) and Rancho OGA (ICC$_{3,2} = 0.53$).\textsuperscript{25}

Spearman’s rank nonparametric correlation analysis tests revealed similar numbers to both the Kappa statistic tests and ICC$_{3,2}$ tests. Rater 1 vs Rater 2 for GARS-M ($r_s = 0.41$) and for Rancho OGA ($r_s = 0.31$). Rater 1 live vs video rescore for GARS-M ($r_s = 0.65$) for Rancho OGA ($r_s = 0.65$). Rater 2 live vs video rescore for GARS-M ($r_s = 0.49$) for Rancho OGA ($r_s = 0.56$).

Chi-square analysis for all inter-rater and intra-rater reliability tests revealed significant differences for all values. Rater 1 vs Rater 2 for GARS-M ($p < .001$) for Rancho OGA ($p = .008$). Rater 1 live vs video rescore for GARS-M ($p < .001$) for Rancho OGA ($p < .001$). Rater 2 live vs video rescore for GARS-M ($p < .001$) for Rancho OGA ($p < .001$).

The 2X2 contingency table comparison analysis between GARS-M and Rancho OGA revealed a low sensitivity ($Sn = 0.20$), high specificity ($Sp = 0.96$), a high positive likelihood ratio ($+LR = 13.6$), a low likelihood ratio ($-LR = 1.03$), positive predictive value ($+Pv = 0.50$), negative predictive value ($-Pv = 0.94$), diagnostic odds ($DO = 16.75$), and number needed to diagnose ($NND = 2.25$). See Table 4 for set up and details.

Comparisons between GAITRite® and Mobility Lab™ were examined by through the implementation of paired sample t-test analyses. These results revealed no significant differences between GAITRite® and Mobility Lab™ in terms of stride length ($p = 0.189$), cadence ($p = 0.357$), cycle time ($p = 0.338$), stride velocity ($p = 0.214$), double support percentage of cycle ($p = 0.375$), swing
percentage of cycle (p=0.126), and stance percentage of cycle (p=0.161)

Results from paired sample t-test analyses including the mean, standard
deviation, standard error of the mean, and p values for both GAITRite® and
Mobility Lab™ are depicted in Table 5.

Pearson correlation analysis was performed to examine the degree of
agreement between both high-technology tools for each variable. The Pearson
correlation coefficients showed that there were significant associations in
cadence (r= 0.685, p < 0.001; Figure 4), gait cycle time(r= .678, p < 0.001; Figure
5), and double limb support time (r=0.270, p =0.026; Figure 7) between Mobility
Lab™ and GAITRite®. There were not significant associations between the 2
methods in stride length(r=0.187; p=0.128; Figure 3), stride velocity(r=0.164,
p=0.180; Figure 6), stance percent of cycle (r =0 .035, p=0.778; Figure 8), and
swing percent of cycle (r=0 .186, p= 0.128; Figure 9).

**DISCUSSION**

With high rates of gait disturbances affecting a significant number of
people the need for affective treatment and prevention is important. With such a
wide variety of gait analysis methods available, it is important to choose the
method best suited for the researcher’s or clinician’s needs based on the patient,
research purpose, budget, time, and available space.

Each gait analysis tool used in this study presents both advantages and
disadvantages with its use. Factors such as reliability, usability, cost, required
training, set up time, required equipment and required space are factors that are
commonly considered when choosing the analysis tool most appropriate for a given setting and specific patient population.

Due to the observational nature of the GARS-M and the Rancho OGA, the data gathered were far less sensitive to joint angles and other quantitative deviations within the gait cycle and therefore these tools were not as sensitive for picking up minor gait deviations in a population of healthy young adults with no reported major gait deficits. However, the measured high specificity of 0.96 and positive likelihood ratio of 13.6 suggest these tools may be useful in ruling in the presence of a major gait deviation. Qualitative analyses of the GARS-M and the Rancho OGA depict both tools as being relatively inexpensive and require little time to administer which may be paramount in choosing to use such tools within the clinical realm. Fair to moderate inter-rater reliability scores and moderate intra-rater reliability scores suggests a degree of subjectivity exists between testers as well as variation in scores on the same subject between live and video rescores.

Results from the repeated measures paired t-tests for high technology gait analysis tools showed no significant difference in any of the seven investigated gait variables. This indicates that the measurements of gait are similar between the GAITRite® and Mobility Lab™. However, Pearson correlation analysis showed a significant correlation between only three of the seven measured gait variables. These discrepancies suggest the two portable high technology gait analysis tools may not be reliable for interchangeable scoring on the same patient. These high technology analysis tools allow for the collection of detailed
objective data that may be beneficial to a clinician or researcher and may not be available when using low technology observational analyses.

This study offered a unique chance to evaluate four gait analysis tools from a vast variety of gait analysis methods. It is important to reiterate the absence of a gold standard technique for gait analysis leaves the clinician and researcher with important decisions to make with regards to choosing their analysis method. To better aid clinicians and researchers, information on the psychometric properties of tools can be found in such resources as the Guide to Physical Therapist Practice, the National Institutes of Health toolbox, Strokengine, and the Neurology Section of the American Physical Therapy Associations Outcome Measures Recommendations resources.

Further research examining high technology and low technology based gait assessments on populations with specific musculoskeletal or neurological gait impairments will be beneficial to further comment on the accuracy, sensitivity, and usability of these tools in specific settings. Continued studies examining response of patient populations to specific rehabilitation interventions with a strong evidence base using similar sampling of tools used in gait analysis including portable technologies that yield data useful in the clinic and for research will be important to further investigate whether these tools are sensitive to change when actual change has occurred.
LIMITATIONS

This study had limitations that must be considered when interpreting or applying findings. The sample of subjects that participated in this study had a narrow age range (mean age 24.5, range 18 to 41) which does not accurately represent the general population as a whole. Another limitation is this sample of participants included physically healthy individuals and excluded any participants with acute orthopedic or known neurologic injuries affecting their ability to walk distances of 100 feet or greater. This therefore minimized gait variations and made the subjects’ gait difficult to assess using the less sensitive observational tools.

The low technology observational gait tools were implemented by DPT students with a basic foundation in gait assessment. The addition of examiners with more clinical experience in gait assessment will be beneficial for future research on the reliability of observational gait analysis tools.

We acknowledge that technology is an ever-growing and constantly developing field which is constantly yielding new instruments for gait analysis. We were not able to include every gait analysis tool and chose to use two high technology tools that were available at the time of our study.

CONCLUSION

This study found the GARS-M to be a quick and easy tool to use that requires little instruction and may be feasible as an outcome measure for persons with significant gait impairments. The GARS-M does not provide
sensitive measurements and is not recommended for analyzing minor gait disturbances. The Rancho OGA offers a much more in depth gait analysis that will require more time and relies heavily on the administrator’s ability to detect variations within the eight phases of gait. With the addition of video cameras and inter/intra reliability measures the Rancho OGA may be a feasible qualitative measure in the research laboratory. The GAITRite® is the closest to a gold standard method of gait analysis used due to its establishment in multiple research studies and lack of a true gold standard quantitative gait analysis method. However of the tools examined in this study the GAITRite® is the most expensive, has the longest set up time, requires the most space, and requires the most technical training to administer making this method better suited for a research setting. The Mobility Lab™ may be the most suitable for both clinical and research use as it offers objective data combined with established clinical measures and more favorable usability factors as compared to GAITRite®, such as less required space and less required technical understanding of the software in order to be used effectively.
**APPENDIX A – Tables**

**Table 1.** Participant Demographics

<table>
<thead>
<tr>
<th></th>
<th>N ( % of total)</th>
<th>Height (cm)</th>
<th>Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong></td>
<td>73 (100%)</td>
<td>170.36</td>
<td>68.9</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>33 (45%)</td>
<td>177.5</td>
<td>77</td>
</tr>
<tr>
<td>Female</td>
<td>40 (54%)</td>
<td>164.3</td>
<td>62</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean = 24.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD = 4.39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(18-24)</td>
<td>41 (55%)</td>
<td>167.7</td>
<td>66.6</td>
</tr>
<tr>
<td>(25-34)</td>
<td>28 (38%)</td>
<td>173.2</td>
<td>71.3</td>
</tr>
<tr>
<td>(&gt;34)</td>
<td>5 (7%)</td>
<td>176.4</td>
<td>74.1</td>
</tr>
<tr>
<td><strong>Had a fall in</strong></td>
<td>5 (7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>the last year?</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5 (7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>69 (93%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualitative Comparisons Across Gait Tools</td>
<td>GARS-M</td>
<td>Rancho OGA</td>
<td>Mobility Lab™</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>--------</td>
<td>------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Set up time Required</td>
<td>No set up time</td>
<td>No set up time</td>
<td>Approximately 10 minutes</td>
</tr>
<tr>
<td>Equipment Required</td>
<td>Writing utensil, GARS-M form, Optional video</td>
<td>Writing utensil, Ranch OGA form, Optional video</td>
<td>Computer with Mobility Lab™ software, Mobility Lab™ sensors</td>
</tr>
<tr>
<td>Training Required</td>
<td>None required</td>
<td>Understanding of gait cycle</td>
<td>Software tutorial</td>
</tr>
<tr>
<td>Space Required</td>
<td>Minimum desired walking distance</td>
<td>Minimum desired walking distance</td>
<td>Minimum desired walking distance</td>
</tr>
<tr>
<td>Subject must be prepped or fitted with equipment?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Table 3. Intra-rater and Inter-rater Reliability

<table>
<thead>
<tr>
<th>Reliability of Low Technology Clinical Observation Tools</th>
<th>% agreement</th>
<th>Kappa</th>
<th>Spearman’s r</th>
<th>ICC</th>
<th>Chi-square (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intra-rater</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1 (JM) GARS-M live vs video rescore</td>
<td>96%</td>
<td>0.650</td>
<td>0.650</td>
<td>0.648</td>
<td>0.000</td>
</tr>
<tr>
<td>Rater 2 (BS) GARS-M live vs video rescore</td>
<td>95%</td>
<td>0.473</td>
<td>0.490</td>
<td>0.476</td>
<td>0.000</td>
</tr>
<tr>
<td>Rater 1 (JM) Rancho live vs video rescore</td>
<td>90%</td>
<td>0.648</td>
<td>0.648</td>
<td>0.643</td>
<td>0.000</td>
</tr>
<tr>
<td>Rater 2 (BS) Rancho live vs video rescore</td>
<td>88%</td>
<td>0.540</td>
<td>0.558</td>
<td>0.543</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Inter-rater</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater 1 (JM) vs Rater 2 (BS) GARS-M</td>
<td>93%</td>
<td>0.408</td>
<td>0.411</td>
<td>0.412</td>
<td>0.000</td>
</tr>
<tr>
<td>Rater 1 (JM) vs Rater 2 (BS) Rancho</td>
<td>81%</td>
<td>0.306</td>
<td>0.307</td>
<td>0.309</td>
<td>0.008</td>
</tr>
</tbody>
</table>
**Table 4. GARS-M and Rancho OGA Contingency Table**

<table>
<thead>
<tr>
<th>Rancho OGA Cases</th>
<th>GARS-M Cases n (%)</th>
<th>Controls n (%)</th>
<th>+ Predictive Value = 0.500</th>
<th>Number Needed to Diagnose = 2.254</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases n (%)</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GARS-M Controls n (%)</td>
<td>4</td>
<td>67</td>
<td>- Predictive Value = 0.944</td>
<td></td>
</tr>
<tr>
<td>Sensitivity = 0.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ Likelihood Ratio = 13.600</td>
<td></td>
<td>- Likelihood Ratio = 1.030</td>
<td>Diagnostic odds = 16.750</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5. Results from GAITRite® and Mobility lab™**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mobility Lab™ (mean)</th>
<th>Mobility Lab™ Std. deviation</th>
<th>Mobility Lab™ (SEM)</th>
<th>GAITRite (mean)</th>
<th>GAITRite Std. deviation</th>
<th>GAITRite (SEM)</th>
<th>Paired t test significance</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride length (m)</td>
<td>1.653</td>
<td>1.815</td>
<td>.220</td>
<td>1.364</td>
<td>.153</td>
<td>.019</td>
<td>.189</td>
<td></td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>108.52</td>
<td>4</td>
<td>6.981</td>
<td>.847</td>
<td>109.150</td>
<td>.7025</td>
<td>.852</td>
<td>.357</td>
</tr>
<tr>
<td>Cycle Time (sec)</td>
<td>1.111</td>
<td>.0735</td>
<td>.009</td>
<td>1.104</td>
<td>.072</td>
<td>.009</td>
<td>.338</td>
<td></td>
</tr>
<tr>
<td>Stride Velocity (m/s)</td>
<td>1.493</td>
<td>1.614</td>
<td>.196</td>
<td>1.250</td>
<td>.141</td>
<td>.017</td>
<td>.214</td>
<td></td>
</tr>
<tr>
<td>Double Support %</td>
<td>24.748</td>
<td>6.356</td>
<td>.771</td>
<td>25.416</td>
<td>2.480</td>
<td>.301</td>
<td>.375</td>
<td></td>
</tr>
<tr>
<td>Swing % cycle</td>
<td>38.109</td>
<td>4.684</td>
<td>.568</td>
<td>37.241</td>
<td>1.256</td>
<td>.152</td>
<td>.126</td>
<td></td>
</tr>
<tr>
<td>Stance % cycle</td>
<td>61.980</td>
<td>4.417</td>
<td>.536</td>
<td>62.76</td>
<td>1.256</td>
<td>.152</td>
<td>.161</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. APDM Mobility Lab™ and GAITRite® Systems

Arrows indicate sensor placement, GAITRite® mat outlined.
Figure 2. Research Flow Chart

Consent Form Completion and Eligibility Screening (N=73)

Leg Length Measurement and Mobility Lab Sensor Placement

2 minute walk at SSWS

GAITRite walkway - Spatiotemporal gait analysis

Mobility Lab Sensor Measurement - Spatiotemporal gait analysis

Microsoft Kinect Recording - 2D body mapping

Sagittal and frontal plane

Rancho Los Amigos Gait Assessment - Clinical Gait

GARS - Clinical Gait Tool

Analyzed (N=73)

1 participant declined

equipment malfunction rendered mobility lab data for 5 subjects unusable

Data Recorded for Future Research
Figure 3. The Pearson Correlation Coefficient of stride length between MobilityLab™ and GAITRite® ($r = 0.187$; $p = 0.128$).

Figure 4. The Pearson Correlation Coefficient of cadence between MobilityLab™ and GAITRite® ($r = 0.685$; $p < 0.001$).
**Figure 5.** The Pearson Correlation Coefficient of cycle time between MobilityLab™ and GAITRite® ($r = 0.678; \ p < 0.001$).

![Graph showing the Pearson Correlation Coefficient of cycle time between MobilityLab™ and GAITRite®](image)

**Figure 6.** The Pearson Correlation Coefficient of stride velocity between MobilityLab™ and GAITRite® ($r = 0.164; \ p = 0.180$).

![Graph showing the Pearson Correlation Coefficient of stride velocity between MobilityLab™ and GAITRite®](image)
Figure 7. The Pearson Correlation Coefficient of double support % between MobilityLab™ and GAITRite® (r = 0.270; p = 0.026).

![Figure 7](image_url)

Figure 8. The Pearson Correlation Coefficient of stance % cycle between MobilityLab™ and GAITRite® (r = 0.035; p = 0.778).

![Figure 8](image_url)
Figure 9. The Pearson Correlation Coefficient of swing % cycle between MobilityLab™ and GAITRite® ($r = 0.186; p = 0.128$).
APPENDIX C

Scores were circled.

Modified Gait Abnormality Rating Scale (GARS-M)

(VanSwearingen, 1996)

1. Variability—*a measure of inconsistency and arrhythmicity of stepping and/or arm movements*:

   0 = fluid and predictably paced limb movements
   1 = occasional interruptions (changes in speed) approximately 25% of the time
   2 = unpredictability of rhythm approximately 25%-75% of the time
   3 = random timing of limb movements

2. Guardedness—*hesitancy, slowness, diminished propulsion, and lack of commitment in stepping and arm swing*

   0 = good forward momentum and lack of apprehension in propulsion
   1 = center of gravity of head, arms, and trunk (HAT) projects only slightly in front of push-off, but still good arm-leg coordination
   2 = HAT held over anterior aspect of foot and some moderate loss of smooth reciprocation
   3 = HAT held over rear aspect of stance-phase foot and great tentativeness in stepping

3. Staggering—*sudden and unexpected laterally directed partial losses of balance*

   0 = no losses of balance to side
   1 = a single lurch to side
   2 = two lurches to side
   3 = three or more lurches to side

4. Foot contact—*the degree to which heel strikes the ground before the forefoot*
0 = very obvious angle of impact of heel on ground
1 = barely visible contact of heel before forefoot
2 = entire foot lands flat on ground
3 = anterior aspect of foot strikes ground before heel

5. Hip ROM—*the degree of loss of hip range of motion seen during a gait cycle*
   0 = obvious angulation of thigh backward during double support (10°)
   1 = just barely visible angulation backward from vertical
   2 = thigh in line with vertical projection from ground
   3 = thigh angled forward from vertical at maximum posterior excursion

6. Shoulder extension—*a measure of the decrease of shoulder range of motion*
   0 = clearly seen movement of upper arm anterior (15°) and posterior (20°) to vertical axis of trunk
   1 = shoulder flexes slightly anterior to vertical axis
   2 = shoulder comes only to vertical axis or slightly posterior to it during flexion
   3 = shoulder stays well behind vertical axis during entire excursion

7. Arm-heel-strike synchrony—*the extent to which the contralateral movements of an arm and leg are out of phase*
   0 = good temporal conjunction of arm and contralateral leg at apex of shoulder and hip excursions all of the time
   1 = arm and leg slightly out of phase 25% of the time
   2 = arm and leg moderately out of phase 25%-50% of the time
   3 = little or no temporal coherence of arm and leg
## APPENDIX D – Rancho Los Amigos Observational Gait Analysis

### Gait Analysis: Full Body

**Rancho Los Amigos National Rehabilitation Center Physical Therapy Department**

<table>
<thead>
<tr>
<th>Reference Limbs:</th>
<th>L</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor Deviation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pelvis</th>
<th>Hikes</th>
<th>Tilt: P/A</th>
<th>Lacks Forward Rotation</th>
<th>Lacks Backward Rotation</th>
<th>Excess Forward Rotation</th>
<th>Excess Backward Rotation</th>
<th>Ipsilateral Drop</th>
<th>Contralateral Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>Flexion: Limited</td>
<td>Excess</td>
<td>Past Retract</td>
<td>Rotation: IR/ER</td>
<td>AD/Abduction: AD/AB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>Flexion: Limited</td>
<td>Excess</td>
<td>Wobbles</td>
<td>Hyperextends</td>
<td>Extension Thrust</td>
<td>Varus/Valgus: Vv/Vl</td>
<td>Excess Contralateral Flex</td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>Forefoot Contact</td>
<td>Foot Flat Contact</td>
<td>Foot Slap</td>
<td>Excess Plantar Flexion</td>
<td>Excess Dorsiflexion</td>
<td>Inversion/Eversion: Iv/Ev</td>
<td>Heel Off</td>
<td>No Heel Off</td>
</tr>
<tr>
<td>Toes</td>
<td>Up</td>
<td>Inadequate Extension</td>
<td>Clawed/hammered: Cl/Ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Major Problems:

- **(WA)** Weight Acceptance
- **(SLS)** Single Limb Support
- **(SLA)** Swing Limb Advancement

### Excessive UE Weight Bearing

Name

Patient #

Diagnosis
References


Curriculum Vitae

John McConnell

Education

- University of Nevada, Las Vegas
  o 2012-Present: DPT, Doctor of Physical Therapy
  o Expected graduation May 2015
- Brigham Young University
  o 2007-2012: B.S., Business Management

Significant Coursework

- Human Anatomy and Physiology
- Evidence Based Research
- Exercise Physiology
- Orthopedic Principles, Assessment and Rehabilitation
- Neuroanatomy, Physiology and Rehabilitation
- Research Statistics
- Pediatrics
- Prosthetics and Orthotics

Clinical Experience

- Comprehensive Physical Therapy – Pahrump, NV
  o June 2013 – August 2013
  o Outpatient Orthopedic setting
- Healthsouth Rehabilitation Hospital – Mesa, AZ
  o July 2014 – October 2014
  o Inpatient Rehabilitation setting
- Phoenix VA Hospital – Phoenix, AZ
  o October 2014 – December 2014
  o Inpatient Acute care setting
- Physiotherapy Associates, Scottsdale Sport Clinic – Scottsdale, AZ
  o January 2015 – April 2015
  o Outpatient Orthopedic and Sports Rehab setting

Professional Membership

- American Physical Therapy Association (APTA)
  o 2012 – Present
Brian Silverman

Education

- University of Nevada, Las Vegas
  - 2012-Present: DPT, Doctor of Physical Therapy
  - Expected graduation May 2015
- University of Nevada Las Vegas
  - 2010-2012: B.S., Kinesiology

Significant Coursework

- Human Anatomy and Physiology
- Evidence Based Research
- Exercise Physiology
- Orthopedic Principles, Assessment and Rehabilitation
- Neuroanatomy, Physiology and Rehabilitation
- Research Statistics
- Pediatrics
- Prosthetics and Orthotics

Clinical Experience

- MVP Physical Therapy – Port Orchard, WA
  - June 2013 – August 2013
  - Outpatient Orthopedic setting
- Desert Springs Hospital – Las Vegas, NV
  - July 2014 – October 2014
  - Inpatient Rehabilitation setting
- San Luis Sports Therapy – San Luis Obispo, CA
  - October 2014 – December 2014
  - Outpatient Orthopedic setting
- Southern Hills Hospital – Las Vegas, NV
  - January 2015 – April 2015
  - Acute Care and Wound Care setting

Professional Membership

- American Physical Therapy Association (APTA)
  - 2012 - Present