CHANGES IN GAIT AND COORDINATION VARIABILITY IN PERSONS WITH MULTIPLE SCLEROSIS FOLLOWING A REHABILITATION PROGRAM

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This study investigated changes in gait and coordination variability in persons with Multiple Sclerosis (MS) after an 8-week rehabilitation intervention. Data for eight participants (Control: 4, Intervention: 4) were analyzed via Cortex Motion Analysis software and Visual 3D to calculate knee and ankle joint angles as well as discrete spatiotemporal parameters. The knee and ankle joint angles were further analyzed using a vector coding technique to quantify coordination between these joints and how they produce a functional gait pattern. No significant changes in gait or coordination variability were found after rehabilitation, but some meaningful changes with large and moderate effect sizes were present. This study demonstrated a comprehensive overview of the relationship between process and outcome variability in a clinical population.

KEYWORDS: coordination, process, walking, Dynamical Systems Theory

INTRODUCTION: Multiple Sclerosis (MS) is a progressive disease in which widespread dysfunction occurs as a result of damage to the central nervous system (Noseworthy, Lucchinetti, Rodriguez, & Weinshenker, 2000). Walking impairment is one of the most commonly reported symptoms in this population, having the largest impact on quality of life (Larocca, 2011). Analyses of MS gait, focused on the measurement of discrete spatiotemporal parameters, have indicated that persons with MS walk slower, take slower, shorter steps, and spend more time in double limb support during their gait cycle than healthy controls (Sosnoff, Weikert, Dlugonski, Smith, & Motl, 2011).

Increasing evidence has shown that gait variability is a quantifiable indicator of walking function (Stergiou, Harbourne, & Cavanaugh, 2006), which has been related to increased fall risk (Hausdorff, Rios, & Edelberg, 2001). Increased gait variability has been noted in persons with neurological conditions such as MS (Crenshaw, Royer, Richards, & Hudson, 2006). Persons with MS have increased gait variability and risk of falling, higher energetic cost of walking (Sosnoff et al., 2011), and less stable gait patterns (Crenshaw et al., 2006), which may be a result of inflexibility in the movement system. Producing a stable gait pattern is a complex process requiring a flexible and coordinated movement system. Gait variability has traditionally been viewed as a limitation for successful locomotion (Hausdorff et al., 1998). Increasing evidence has shown that variability in movement system patterns is imperative to produce the flexibility necessary for successful task execution (Van Emmerik et al., 1999). As a result, movement system variability is viewed as functional when a consistent skill outcome can be achieved through varying patterns of coordinated movement (Van Emmerik & Van Wegen, 2002). Variability in motor task performance has previously been reported as negative (Lockhart & Stergiou, 2013), although this only measures outcome variability and ignores the movement system patterns used to accomplish the task.

Variations in the relationship between process and outcome variability and their codependent contribution to an overall functional system has been well documented in skill acquisition and sport (Wilson, Simpson, Emmerik, & Hamill, 2008; Mitra, Amazeen, & Turvey, 1998). Bernstein's (1967) classical ideas reflect the notion that a person's process variability increases with skill

level, while Mitra et al.'s (1998) viewpoint disputes these findings and suggests the opposite. Wilson et al. (2008) presented a combination of the previous findings reporting that this change in process variability is "U-shaped" instead of linear. To date, there has been no application of any variation of this relationship in clinical populations. If consistent stride characteristics are considered the desirable outcome, the movement patterns used to accomplish a consistent outcome must also be considered.
The purpose of the current study was to assess the change in gait and coordination variability in persons with Multiple Sclerosis after an 8-week rehabilitation program.

METHODS: Eight female participants (Mean ± SD: 164.4 ± 5.9 cm; 78 ± 24.6 kg) participated in the study. Approval for this study was granted by the Human Subjects Institutional Review Board of Northern Michigan University, Marquette, Michigan, USA (IRB# HS17-870). Inclusion criteria required participants to be in a stable phase of their MS, have chronic progressive pattern or relapsing-remitting MS with no relapse during the past three months, and have an Expanded Disability Status Scale (EDSS) score between 5 and 7 (Kurtzke, 1983). Participants were excluded if they had any cardiac related risk factor, major orthopedic problems or contractures of the lower limbs, complete inability to stand or walk for a longer period than three months, significant medical comorbidities, and cognitive or psychiatric problems that could compromise compliance with physical therapy. Participants who met all the inclusion criteria completed an informed consent.
Testing took place before and after an 8-week intervention. On each day of testing, participants completed a total of six 10 m walking trials; three trials without and three trials with the NewGait™ device. For the current study only the trials without the NewGait™ device were reported. Thirty four retroreflective markers were placed bilaterally on each participant's Anterior Superior Iliac Spine and Posterior Superior Iliac Spine, medial and lateral knees, medial and lateral ankles, 1st and 5th metatarsal, and calcaneus. Marker clusters were also placed bilaterally at mid-thigh and mid-shank. Kinematics were measured using a 10 camera system (250 Hz), digitized and Butterworth filtered (10 Hz) using Cortex Motion Analysis software (Motion Analysis Corporation, Santa Rosa, CA, USA). For all trials, participants were instructed to "walk as quickly and as safely as you can".
Participants were matched based on similar levels of gait impairment and EDSS scores. The first member of the pair to complete pre-testing was randomized into either the control or intervention group using a single coin flip. Both groups completed an 8 week intervention which included two 60 minute physical therapy sessions per week, all of which included balance, functional balance, gait, and mat exercises. The intervention group also wore the NewGait™ device at all sessions.
Gait and lower limb kinematic data were calculated by creating a conventional gait model using a CODA pelvis created in Visual 3D (Version 4.0, C-Motion, Inc., Germantown, MD, USA), and by following standard Visual 3D protocol for recognition of gait events (Zeni, Richards, & Higginson, 2008). Gait variability was calculated for right and left step length (SL) and double limb support time (DLST) in both the stance and swing phases for each leg. Coefficient of variation was calculated for each of these variables across repeated steps. One intralimb coupling (knee flexion-extension/ankle dorsiflexion-plantarflexion) was calculated using a modified vector coding technique (Needham, Naemi, & Chockalingam, 2014). Kinematic and coordination time-series data were separated into stance and swing phases and normalized to 101 data points. Variability of the normalized coupling angles time series was calculated on a point by point basis for the swing phase and the first and second half of the stance phase using circular statistics (Needham et al., 2014). Participants were categorized according to walking ability using their 6 m walk times (novice >0.6 m/s, experienced > 1 m/s and experts >1.2 m/s) (Fritz & Lusardi (2009)).

A repeated measures mixed ANOVA was used to assess the change in gait and coordination variability across time and between groups. Statistical analyses were completed with SPSS (version 24). Cohen's *d* effect sizes (ES) were calculated to assess change across time for each group. Interpretation of ES were based on the scale for effect size classification of Hopkins (2000): < 0.04 = trivial, 0.041-0.249 = small, 0.25-0.549 = medium, 0.55-0.799 = large, and >0.8 = very large. Additional paired t-tests were completed to investigate pre-post comparisons within groups when large effect sizes were present.

RESULTS AND DISCUSSION: No group by time interactions were reported therefore the data reported below considers both groups and focuses solely on changes relative to time (pre Vs post). No significant changes were found in gait or coordination variability (Table 1). However, there were some meaningful changes with large and moderate effect sizes, generally indicating decreased gait and coordination variability (Table 1).

Table 1: Mean ± SD, differences, p-values and effect sizes for coordination and gait variability variables for all participants.

	Knee-Ankle Coordination Variability (°)						Gait Variability (CV%)		
	LEFT STANCE		RIGHT STANCE		LEFT SWING	RIGHT SWING	STEP LENGTH		DOUBLE SUPPORT TIME
	PHASE 1	PHASE 2	PHASE 1	PHASE 2			LEFT	RIGHT	
PRE	151.82 ± 40.06	160.52 ± 42.29	139.32 ± 47.27	150.25 ± 42.94	161.31 ± 36.23	161.78 ± 35.47	23.99% ± 36.20 %	9.88% ± 20.98%	10.34% ± 8.65 %
POST	126.12 ± 24.93	134.11 ± 28.11	118.98 ± 34.03	130.99 ± 27.15	148.51 ± 22.95	136.21 ± 28.90	3.92% ± 4.28%	3.90% ± 2.22%	8.49% ± 5.03%
DIFF	25.70	26.41	20.33	19.26	12.81	20.33	20.07%	5.99%	1.85%
p-value	0.28	0.29	0.07	0.13	0.85	0.07	0.13	0.46	0.59
d	0.80	0.73	0.53	0.56	0.52	0.53	0.99	0.52	0.27

These findings are in agreement with those of Stergiou et al. (2006) and Hausdorff et al. (2001), who noted that gait variability is a quantifiable indicator of walking function and is related to increased risk of falling. These decreases in coordination variability could be interpreted to align with Wilson et al. (2008), who suggested that process variability exists as a "U-shape" curve. The data in the current study could be interpreted as shown in Figure 1 where expert performers categorized by walking ability transition to new levels of process variability as they transition into higher categories of walking ability after exploring new complex movement patterns.

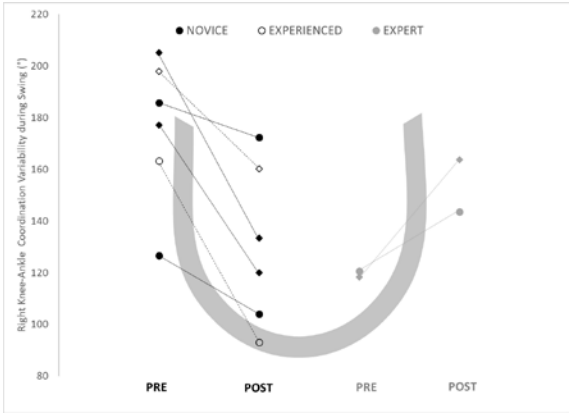

Figure 1. Changes in knee-ankle coordination variability during swing in novice, experienced and expert walkers.

The current study has important implications for persons with MS as the relationship between process and outcome variability is not well documented in clinical populations. Understanding this relationship may provide clinicians with a useful clinical indicator and provide insight on the required length of an intervention to allow appropriate time for the exploration of more complex movement patterns.

A limitation of the current study was the lack of power due to the small sample size as only a subsample from an ongoing study was used. A second limitation was the length of the intervention. A longer intervention may have given participants time to explore more complex movement patterns,

allowing them to move closer to “expert”. Future research should focus on reproducing the current study with a longer intervention, larger sample size, and equal numbers for both genders.

CONCLUSION: The study assessed the change in gait and coordination variability in persons with Multiple Sclerosis after an 8-week rehabilitation intervention. No significant changes in gait and coordination variability were evident, but meaningful changes with large and moderate effect sizes were found generally indicating decreased gait and coordination variability with rehabilitation. The study demonstrated a comprehensive overview of the relationship between process and outcome variability in a clinical population.

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