

Immediate Impact of Extremity Manipulation on Dual Task Performance: A Randomized, Crossover Study

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Research

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Abstract

Background: Previous research demonstrated that manipulation of the extremities was associated with changes in multisegmental postural sway as well as improvement in a lower extremity balancing task. We were interested if these effects would extend to an upper extremity task. Our aim in this study was to investigate whether extremity manipulation could influence dual task performance where the explicit suprapostural task was balancing a water filled tube in the frontal plane.

Methods: Participants were healthy volunteers (aged 21-32 years). Upper- or lower-extremity manipulations were delivered in a participant and assessor blinded, randomized crossover, clinical trial. Postural (center of pressure) and suprapostural (tube motion) measurements in the frontal plane were made pre-post manipulation under eyes open and eyes closed conditions using a BTrackS™ force plate and a Shimmer inertial measurement unit, respectively. Pathlength, range, root mean square and sample entropy were calculated to describe each signal during the dual task performance.

Results: There was no main effect of manipulation or vision for the suprapostural task (tube motion). However, follow-up to interaction effects indicates that roll pathlength, range and root means square of tube motion all decreased (improvement) following lower extremity manipulation with eyes open. Regarding the postural task, there was a main effect of manipulation on mediolateral center of pressure such that pathlength reduced with both upper and lower extremity manipulation with larger decreases in pathlength values following upper extremity manipulation.

Conclusion: Our findings show that manipulation of the extremities enhanced stability (e.g. tube stabilization and standing balance) on performance of a dual task. This furthers the argument that site-specific manipulations influence context specific motor behavior/coordination.

Trial Registration: Clinicaltrials.gov, NCT03877367, Registered 15 March 2019,
<https://clinicaltrials.gov/ct2/show/NCT03877367?term=NCT03877367&draw=2&rank=1>

Background

Maintaining an upright stance requires torques be generated around the ankles, knees, hips and even the upper extremities [1–4]. Movement of one part of the body entails compensatory adjustments elsewhere for bi-pedal individuals to maintain their center of mass above their base of support and thus remain standing. In both posture and goal directed "suprapostural" activities, such as reaching or balancing an object with the upper extremities, the control of movement depends on the continuous and accurate regulation of many muscles, joints and limbs [5, 6]. It has been suggested that during these dynamic activities, the arms and trunk may be used to generate restorative torques to reduce the angular momentum of the body [1], which would require proprioceptive information relating to the position of not only the limbs, but also the trunk and head. Accordingly, dynamic postural control seems to require whole body coordination.

Evidence for neurologically based mechanisms of action for spinal manipulative therapy include central changes in sensorimotor and cortical integration [7, 8], as well as peripheral changes to volitional elbow flexor activity [9] and joint position sense [10]. While it has been suggested that the chiropractic profession examine posture from a dynamic perspective, including suprapostural behaviors [4], few research studies have been conducted in this area. There are even fewer research studies exploring the effects of extremity joint manipulation on postural dynamics and/or sensorimotor integration.

We previously conducted a study that examined the effect of upper and lower extremity manipulation on posture and balance [11]. We found that lower extremity manipulation influenced several dynamic measures of postural sway while standing on both the ground and rocker board. That is, extremity joint manipulation of the lower extremities improved the organization of sway for the trunk (anterior-posterior direction) and rocker board (medial-lateral direction) and extremity manipulation of the upper extremities reduced roll range and pathlength on the lower extremity-based rocker board task. We postulated that these effects could be due to a change in sensory input and respective motor output leading to behavioral modifications such as restorative torques and postural sway. Furthermore, the magnitude and direction of the sensorimotor change appeared to be responsive to the task being performed and the joint being manipulated.

As a follow-up to that study, we examined the effects of upper and lower extremity joint manipulations on an upper body task, holding a water-filled tube parallel to the ground. Given that holding a tube while standing is a dual task, we assessed participant's performance with both posturography and an inertial measurement unit (IMU). Our aim was to investigate whether extremity manipulation could influence dual task performance where the explicit suprapostural task was balancing a water filled tube in the frontal plane by the upper extremity. Since vision influences tactile processing [12, 13], we tested participants while standing with both eyes open and closed. We hypothesized: 1) both upper and lower extremity manipulation would reduce tube roll parameters, as well as mediolateral postural sway; 2) upper extremity manipulation would reduce tube roll to a greater extent, and that lower extremity manipulation would reduce postural sway to a greater extent; 3) the presence or absence of vision would also influence task performance.

Methods

Participants

A sample of 23 healthy chiropractic students (78% male) between the ages of 21 and 32 (age: 27.4 ± 2.7 years) were recruited. Participants were recruited from the Parker University student body. Eligible participants had no known musculoskeletal, neurological or visual impairments. Written informed consent was obtained from each participant prior to the start of experimental procedures. Approval to conduct this study was granted by the Institutional Review Board at Parker University (#A-00186), in accordance with the Declaration of Helsinki. All testing was performed at Parker University's Research Center. Registered at ClinicalTrials.gov; (NCT number): NCT03877367).

The sample size for this study was based on a power analysis derived from data found in Malaya et al [11]. We used pre-post standard deviations (SDs) of mean changes in mediolateral (ML) rocker board sample entropy (SampEn) from our previous study [11]. The calculations were based on an estimated effect size of 10% after extremity manipulation. Twenty participants per group would provide at least 80% power to detect a 10% or larger difference at a 0.05 level of significance in mean change pre-post visit.

Study Design

This study was a participant, outcome assessor, and data analyzer blinded, crossover, clinical trial. Participants were randomized into two different groups. Group one received an upper extremity manipulation series on the first day and, after a 24-hour washout period, returned and received a lower extremity manipulation series. Group two received a lower extremity manipulation on the first day and an upper extremity manipulation series on the second day. Participants were assessed on dual task performance before and after receiving joint manipulations on both days.

The joint manipulations were performed distally to proximally and were distal radioulnar, humeroulnar, and glenohumeral (upper extremity series) and tibiotalar, tibiofemoral, and coxofemoral joints (lower extremity series), respectively. Both series were performed bilaterally for each participant and all manipulations were performed by an experienced chiropractor with greater than ten years clinical experience.

[Figure 1 about here - CONSORT]

Dual Task

Participants were asked to stand comfortably on a Balance Tracking System (BTrackS™, San Diego, CA) force plate with their elbows bent at 90 degrees and hands in line with elbows. They were then handed a capped 2" diameter PVC tube (60.5" long) half-filled with water. Previous research using a similar water filled tube has found that when lifted, water within the tube moves and immediately demands control, stabilization and greater muscle engagement particularly with paraspinal, deltoid, and abdominal muscles [14].

Participants were instructed to "hold the tube level with the ground". Participants held the tube for 30 seconds each under the eyes closed and eyes open conditions. Test order was randomized by participant. Data capture began immediately after the study associate released the tube into the participants hands.

[Figure 2 about here – Experimental Setup]

Data Collection

The tube was fitted with an IMU (Shimmer Sensing) that collected kinematic data. Data were streamed wirelessly at 51.2 Hz to the Consenys v.1.5.0 software platform (Shimmer Sensing) and exported for processing.

Center of pressure (COP) data were collected by a BTrackS™ (Balance Tracking Systems) force plate. Data were acquired through the Explore Balance software application (Balance Tracking Systems, version 2.0.4) at 50 Hz.

Data from the tube and force plate were processed by a custom Matlab script (Matlab R2018b:9.5.0.944444). SampEn, path length (pathlength), range, and root mean square (RMS) were calculated for the roll direction of the tube sensor as well as for the ML COP of the force plate.

Data Analysis

Change scores (post minus pre) were calculated for SampEn, pathlength, range and RMS. These change scores served as the dependent variable in separate analyses for the IMU and COP measures. Statistical analysis of COP and IMU data was performed using a 2×2 factor ANOVA with repeated measures (upper-lower manipulation, eyes open-closed). Post hoc tests were performed using Bonferroni corrected pairwise comparisons. All analyses were conducted using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at an alpha value of 0.05.

Results

Participants

One participant was excluded from randomization due to failure to meet inclusion criteria (outside of age range). No participants were lost to follow-up and all collected data were used in the analysis.

Suprapostural Task

There were no main effects of manipulation or vision for any of the measured dependent variables. However, interactions for roll path length, roll range, roll RMS and roll SampEn were all significant. Post hoc pairwise comparisons were performed for significant interactions with a Bonferroni adjustment applied.

For roll path length, the significant interaction, $F(1,22) = 11.92$, $p = 0.002$, $\eta^2 = 0.351$ with follow up comparisons showed a significant effect of lower extremity manipulation with vision ($p = 0.022$). Specifically, there was a reduction in roll path length following lower extremity manipulation with eyes open (mean = -190.82 degrees; 95% CI, -358.27 to -23.37) compared to eyes closed (mean = 17.74 degrees; 95% CI, -130.69 to 166.16).

For roll range, the significant interaction, $F(1,22) = 7.27$, $p = 0.013$, $\eta^2 = 0.248$ with follow up comparisons showed a significant effect of lower extremity manipulation with vision ($p = 0.030$). Roll range reduced to a greater extent following lower extremity manipulation with eyes open (mean = -6.01 degrees; 95% CI, -10.42 to -1.60) compared to eyes closed (mean = -1.10 degrees; 95% CI, -4.45 to 2.25).

For roll RMS, the significant interaction, $F(1,22) = 12.89$, $p = 0.002$, $\eta^2 = 0.37$ with follow up comparisons also showed a significant effect of lower extremity manipulation with vision. Roll RMS also reduced to a

greater extent following lower extremity manipulation with eyes open (mean = -0.60 degrees; 95% CI, -0.99 to -0.22) compared to eyes closed (mean = -0.15 degrees; 95% CI, -0.48 to 0.19).

For roll SampEn, the significant interaction, $F(1,22) = 4.95$, $p = 0.037$, $\eta^2 = 0.184$ did not produce any significant follow up comparisons.

Postural Task

There was a main effect of manipulation for ML pathlength, $F(1,22) = 9.92$, $p = 0.005$, $\eta^2 = 0.31$. Pre-manipulation values were larger than post manipulation values. Both manipulation types reduced ML COP pathlength. Upper extremity manipulation reduced COP to a greater extent (mean = -7.14 centimeters; 95% CI, -10.80 to -3.47) than lower extremity manipulation (mean = -2.83; 95% CI, -5.22 to -0.43). No main effect of vision was found and there was no interaction of vision and manipulation.

There was also a main effect of manipulation for ML RMS, $F(1,22) = 5.28$, $p = 0.032$, $\eta^2 = 0.19$. Mean pre-manipulation values were larger than post manipulation values for lower extremity manipulations, hence lower extremity manipulations reduced COP RMS (mean centimeters = -0.25; 95% CI, -0.52 to 0.01). Mean pre-manipulation values were less than post manipulation values for the upper extremity and thus increased COP RMS (mean = 0.29; 95% CI, -0.054 to 0.62). No main effect of vision was found and there was no interaction of vision and manipulation either.

No significant main effects or interactions were found for the Range or SampEn dependent measures involving ML sway on the force plate.

Discussion

Participants in this study were asked to simultaneously perform a postural and suprapostural dual task before and after receiving either a lower or upper extremity manipulation. Both upper- and lower-extremity manipulation influenced dual task performance. Lower extremity manipulation with eyes open significantly reduced tube motion as assessed by roll pathlength, range and RMS, whereas both upper and lower extremity manipulation reduced COP movement on a force plate as assessed by ML postural sway. SampEn, a measure of movement structure and periodicity, provided no further insight into tube roll or postural sway, in contrast to our expectations from previous work.

Research on spinal manipulation has shown changes in volitional muscle activity [9], voluntary range of motion [15], biomechanical and structural changes [16], complex whole-body motor response task [17], movement time [18] and joint position sense [19]. As their effects extend beyond the local anatomical area of manipulation, it has been postulated that these changes may be driven by downstream cortical stimulation rather than spinal or local influences [20]. Similarly, in this study, we found that chiropractic manipulation of the extremities influenced both upper and lower extremity-based task performance.

In this study, participants' performance on the tube balancing task was modulated by an interaction between lower extremity manipulation and the participants' visual condition. In the eyes open condition,

lower extremity manipulation led to decreased values of tube roll parameters, indicating enhanced stability. The importance of visual information to joint manipulative effects is inherently pragmatic/useful, as most chiropractic patients are utilizing visual information throughout their daily activities; however, it is still not known how the central nervous system combines relevant somatosensory and visual information for such control. One possibility may be that (“noninformative”) vision improves haptic perceptions of peripersonal space [13]. More work is needed to better understand the relationship between manipulation and vision.

The interplay between the visual and somatosensory systems has been elicited in many postural studies, particularly in work concerning muscle and tendon vibration. Mancheva et al [21] found that motor evoked potentials from transcranial magnetic stimulation during tendon vibration varied depending on whether subjects’ eyes were open or closed [21]. Lackner and Levine [22] showed simultaneous vibration of the neck and Achilles tendons could induce nystagmoid eye movements and Bove et al [23] found that vibration over postural muscles could alter proprioceptive integration, leading to changes in body tilt and rotation [22, 23]. From our findings, we propose that joint manipulation of the extremities may stimulate the same primary and secondary afferents stimulated by muscular and tendon vibration and that these changes in somatosensation can facilitate cortical changes and alter motor outputs [20, 24–26].

According to Pacheco et al [27] in the ecological theory of perception and action, enhanced stability (e.g. tube stabilization) occurs from the attunement of the perceptual systems to task dynamics together with modifications of action as task and intrinsic dynamics cooperate and/or compete. Chiropractic manipulation may then modulate the properties of the perceptual-motor workspace of participants. The prevailing thought on the neurophysiological impact of spinal/extremity manipulation is one of perceptual attunement brought about by mechanisms related to greater afferentation by peripheral receptors [28–30]; however, our consistent interaction effects suggest the modulation of visual perception may also be a possibility. Furthermore, the action capabilities of the participant are likely promoted by enhanced neural drive through supraspinal, spinal or extremity-based mechanisms [20, 31, 32].

As described in the introduction, previous work by this team found that ipsilateral upper and lower extremity manipulations affected participant performance during a lower extremity balance task (standing on a rocker board) [11]. In that study, both upper and lower extremity manipulations led to decreased pathlength as measured on a rocker board. While participants in the current study stood on a force plate (rather than a rocker board), again, both upper and lower extremity manipulation led to decreased ML pathlength (in this case COP pathlength). This is particularly interesting as this effect is found irrespective of whether the manipulations involved a single limb (previous study) or both limbs (current study). While comparing the magnitudes of single vs bilateral limb manipulation effects would be overly speculative given the differences between the two studies, this is an interesting question that could be addressed in future studies.

It is important to note that we did not capture the segmental (or multi-segmental) strategies used by participants in this study. Collecting such data may be able to resolve why contrary to our hypothesis,

upper extremity manipulation had no effect on tube stabilization, but did reduce ML postural sway. Such information would also likely explain why lower extremity manipulation consistently aided tube stability. Despite the opacity of strategies utilized, participant performance is still consistent with an ecological model; joint manipulation afforded participants greater stability during dual task performance. We suggest that further research is necessary to understand how extremity manipulations afforded the aforementioned improvement in performance.

While these results are novel, they require replication. This study is also limited in that it examined only healthy, asymptomatic, adult participants. While many interesting effects can become more pronounced in clinical populations, many effects can also disappear entirely. These results do not currently, and may not necessarily generalize beyond a healthy, asymptomatic population. Future work should investigate these effects in special populations, and, particularly, the elderly, where balance and falls are major factors in injury and loss of independence.

Conclusion

Joint manipulations of the upper and lower extremities enhanced stability across a postural / suprapostural dual task and were modulated by the presence of visual information. They also influenced context specific motor behavior beyond the local anatomical area of the joint being manipulated. These results suggest that a centrally integrative mechanism – similar to that of spinal manipulation – is also present with manipulation of the extremity joints.

Abbreviations

IMU

Inertial Measurement Unit

SD

Standard Deviation

ML

Medial to lateral

SampEn

Sample Entropy

COP

Center of Pressure

Pathlength

Path Length

RMS

Root Mean Square

ANOVA

Analysis of Variance

Declarations

Ethics approval and consent to participate

Ethical approval to conduct this study was granted by the Institutional Review Board at Parker University (#A-00186). Written informed consent was obtained from each participant prior to the start of experimental procedures.

Consent for publication

Consent for using Figure 1 was obtained from the individual pictured.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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No funding was obtained for this study.

Authors' contributions

CM, DS, JH and KP conceived the study. CM, DS, JH and KP designed, coordinated the study and drafted the manuscript. CM, DS, JH and KP were involved in the study-implementation, CM, DS, JH and KP performed the data analysis. CM, DS, JH and KP interpreted the findings. All authors read and revised the manuscript critically and approved the final manuscript.

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Figures

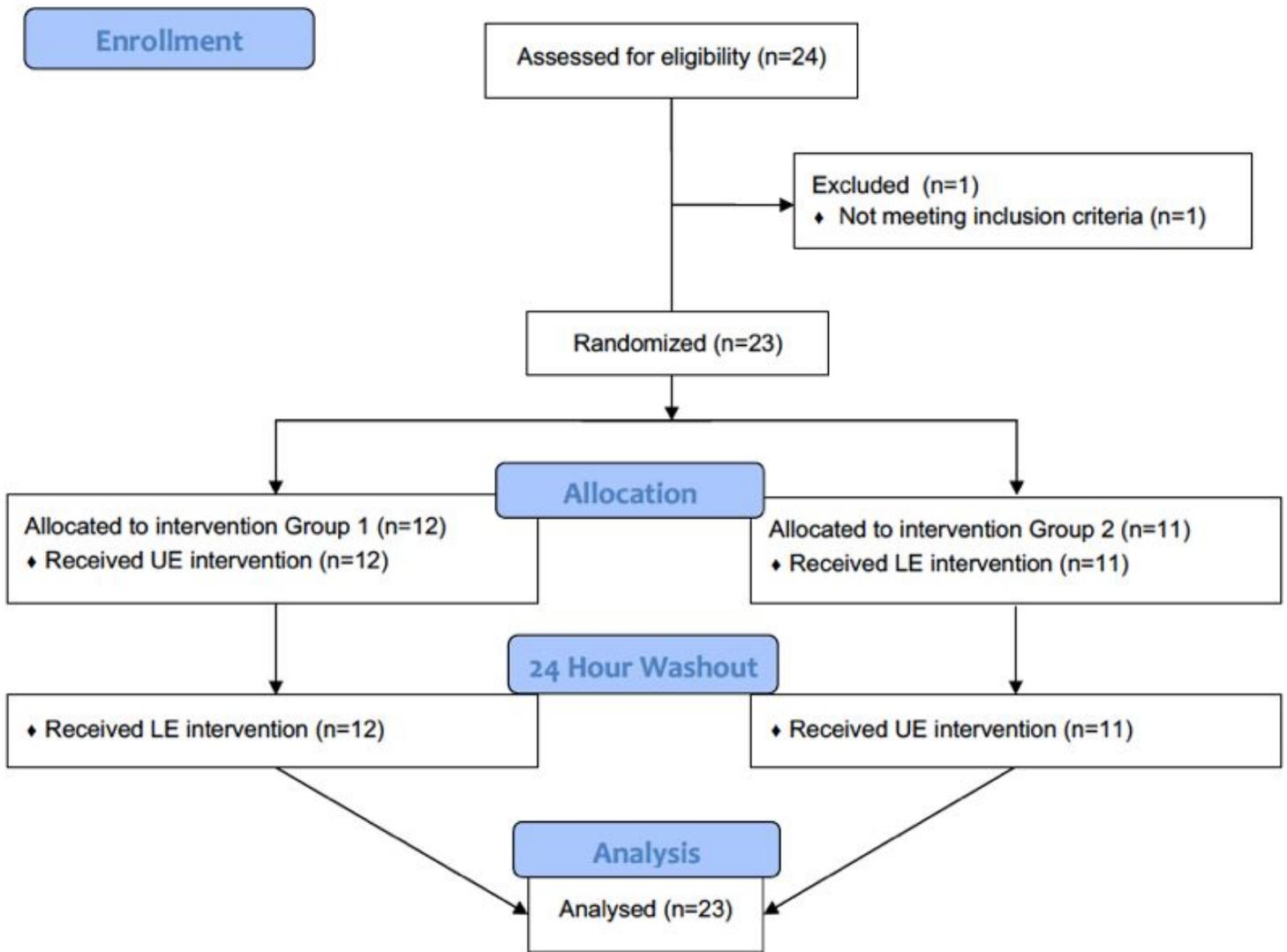


Figure 1

CONSORT



Figure 2

Experimental Setup