THE SHORT-TERM EFFECT OF HIGH-VELOCITY LOW-AMPLITUDE SPINAL MANIPULATION ON KINEMATICS OF MAXIMAL EFFORT SOCCER KICKING: AN EXPLORATORY MULTI-METHODS FEASIBILITY STUDY

Antonio Petrolo, Scott Howitt, and Samuel Howarth

ABSTRACT

Background: Primary research on performance changes in athletes following spinal manipulative therapy (SMT) is inconclusive and lacks methodological rigor. Many studies on post-intervention changes in performance (e.g., kinematics) have been limited by the available instrumentation. Addressing issues of methodological rigor through well-designed pilot/feasibility studies will improve the quality of future trials.

Objective: To assess the feasibility of collecting three-dimensional kinematic data during maximal effort soccer kicking before and after receiving high-velocity low-amplitude (HVLA) SMT of the lumbosacral spine. A secondary objective included the qualitative analysis of comments and feedback from the athletes regarding the protocol, personal experiences of SMT, and the subjective interventional effect on kicking from the study trials.

Methods: Participants were recruited from elite and sub-elite Canadian soccer teams. Each participant performed two sets of maximal effort instep kicks of stationary soccer ball; one before and one after HVLA-SMT of the lumbosacral spine. Three-dimensional kinematic data from the lower extremities, pelvis and thorax, as well as the soccer ball, were monitored throughout all kicking trials. Feasibility was established if at least 90% of participants had at least 70% complete kinematic data. Participants were also briefly interviewed before and after the kicking trials. Questions focused on the participant's definition of performance, their past experiences with chiropractic and spinal manipulation, and their description of whether/how the intervention affected their ability to kick.

Results: Data were collected from twelve participants (2 female). Ten participants (83.3%) had complete kinematic data. Unusable kinematic data for two participants were due to investigator error. Eleven participants reported that the instrumentation did not affect their ability to move, and

nine reported no effect of the “dead time” in between instrumentation, calibration, and kicking trials.

Clinical Implications: Studying if/whether biophysical function changes post-SMT is an interest for both clinical and sport-focused researchers. Findings from this study can be used to inform methodology of future clinical/performance studies.

Conclusion: Acquiring kinematic data from participants performing a complex athletic task in a pre-post SMT intervention study is feasible.

Keywords: soccer, instep kick, feasibility, spinal manipulative therapy, three-dimensional kinematics

INTRODUCTION

Performance enhancement is identified as a research priority for sports-focused chiropractors and a main reason that athletes seek chiropractic care[1,2]. In the context of a chiropractor's scope of practice, the term "chiropractic care" is commonly associated with joint manipulation and/or mobilization[3-5]. chiropractors often perform these manual procedures on athletes to enhance performance, and this may occur irrespective of clinical findings (i.e., performance therapy)[6]. The most recent systematic review on this topic suggests that manipulation for performance benefits is inconclusive and lacks methodological rigor[7]. Thus, additional work in the form of pilot/feasibility studies is necessary to improve the methodological rigor for future clinical studies on the effects of manipulation on sport performance[8-10].

One area of methodological improvement identified by recent feasibility studies has been the acquisition and measurement of neurophysiological and biomechanical outcomes in studies of the effects of high-velocity low-amplitude manipulation on athletic performance[11,12]. Data regarding movement patterns (i.e., kinematics) and the corresponding muscle recruitment (i.e., electromyographic) to create these patterns are fundamental to understanding the physical manifestation that contributes to changes in sport-related performance. In this case, the term "sport-related performance" encompasses outcomes that are relevant to the sport (e.g., driving distance in golf) or relevant to the enhancing an athlete's ability to perform (e.g., better efficiency/economy of movement). Corso and colleagues specifically noted challenges with their chosen motion capture system to acquire usable kinematic data from participants performing maximal effort soccer kicking before and after spinal manipulation directed toward the lumbosacral spine[11]. In addition to the motion capture system, there are several general considerations related to the acquisition and processing of kinematic data for protocols that

employ a pre-post design with manipulation as the intervention. One example is the potential for the placement of kinematic instrumentation to be altered during the administration of treatment, which likely necessitates the removal and the subsequent replacement of the kinematic instrumentation. The selection of the most relevant dependent measurement is also important as the kinematic data can be processed to yield a multitude of variables for investigation[13]. Investigators often will define the most relevant kinematic dependent measurements based on presumed determinants of performance; however, another approach is to consider the participant's/athlete's perspective in a multi-methods design[14,15].

Thus, the objective of the proposed study is to assess the feasibility of collecting three-dimensional kinematic data during maximal effort soccer kicking in a pre-post design with high-velocity low-amplitude manipulation of the lumbosacral spine as the intervention. Maximal effort soccer kicking is chosen as the task since two previous studies have demonstrated improvements in ball velocity with spinal manipulation[11,16]. Information related to the acquisition and processing of kinematic data for future clinical studies on the effects of manipulation on sport performance will be used to assess feasibility. The secondary objective of this study was to analyze qualitative feedback from the athletes regarding the protocol, personal experiences of SMT, and the subjective interventional effect on kicking from the study trials.

METHODS

Overview

An exploratory multi-methods feasibility study was conducted[14]. The protocol described by Corso and colleagues was closely followed in the conducted study[11]. All data collections took place in the Human Performance Lab at the Canadian Memorial Chiropractic College. The

protocols for this investigation were approved by the Research Ethics Board at the Canadian Memorial Chiropractic College (REB# 2208B02).

Subjects

A convenience sample of male and female elite (Canadian Premier League) and sub-elite (League1 Ontario) soccer players were recruited. To be included, the participants were to be able to read and speak English. Exclusion criteria included any self-reported contraindication to lumbosacral spinal manipulation[17], current episode of low back pain at least 2/10 on a Numerical Rating Scale, current lower-limb injury, current pregnancy, and use of any medication that may affect coordination and balance or known allergies to adhesives.

We aimed to recruit a sample of 17 participants for this study. This sample number represents the midpoint of estimates that use the 68% confidence interval and 90% confidence interval, with a lower limit of 0.8, for the expected proportion (90%) of participants that will have no gaps for tracking markers greater than 5 consecutive frames (~0.021 seconds) from start to end of the kicking cycle in at least 70% of all kicking trials[8,22]. The midpoint of these estimates was chosen as a balance between the level of confidence in the expected proportion and pragmatism for collecting the data.

Protocol

Upon the participants' arrival to the lab, inclusion and exclusion criteria were reviewed. This was followed by a review of the study information letter and signing of the informed consent document. Next, an investigator (AP) conducted a brief pre-treatment interview with the athlete. Questions at the start of the protocol focused on the participant's definition of performance and past experiences with chiropractic treatment and spinal manipulation. Audio of all interviews were digitally recorded. The same investigator conducted a physical assessment of the

participant to determine parameters of treatment that would be directed to either the pelvis or lumbar spine. Participants were then instructed to warm up by either riding a stationary bike or running on a treadmill for a period of 10-15 minutes prior to instrumentation.

During instrumentation, specific anatomical landmarks were identified by manual palpation and marked with a washable marker to facilitate replacement after treatment. Both marker clusters (or rigid plastic plates) as well as individual markers were used in the marker placement configuration. Markers affixed to the rigid plastic plates tracked movements of the following anatomical segments: thorax, pelvis, thigh (bilateral), shank (bilateral), and foot (bilateral). Individual marker placement configuration included the top of the head, acromion (bilateral), anterior superior iliac spine (bilateral), greater trochanter (bilateral), iliac crest (bilateral), medial femoral condyle (bilateral), lateral femoral condyle (bilateral), medial malleoli (bilateral), lateral malleoli (bilateral), calcaneus (bilateral), 1st metatarsal head (bilateral), 5th metatarsal head (bilateral), 2nd metatarsal head (bilateral), sternal notch, xyphoid process, 12th rib (bilateral), iliac crest (bilateral), and tibial tubercle (bilateral). Individual kinematic markers were affixed to the participant's shoes and skin using double-sided tape while Velcro® straps were used to secure rigid plastic plates holding clusters of markers to the segments of the participant's lower extremities, pelvis and thorax (Figure 1). Kinematic data from an upright standing trial was then collected. The positioning/posture of the participant was constrained to improve trial-to-trial repeatability. For kicking trials, most individual markers were eliminated, however some remained for the purposes of analyzing the shifting of the rigid bodies throughout the protocol. The markers that remained for the kicking trials included the left and right tibial tubercles, the 12^{th} rib (kicking leg), the suprasternal notch, the xiphoid process and the iliac crest (kicking leg). The rigid plastic plates were not removed.

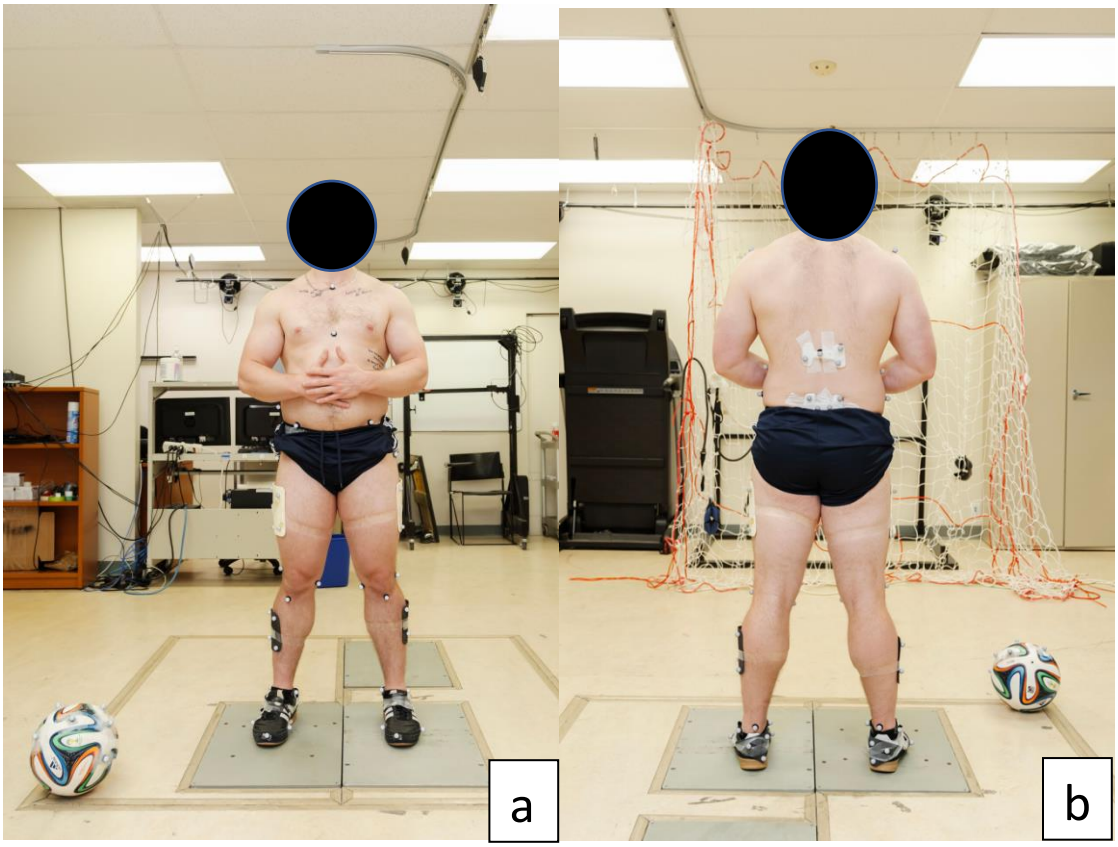

Figure 1 – Anterior (a) and posterior (b) views of the upright standing trial with kinematic markers equipped.

Once participants were appropriately equipped with all instrumentation, an upright standing trial was collected for calibration. Participants were then instructed to perform 3-5 submaximal effort instep soccer kicks with a standardized 3 step run-up. This provided an opportunity for participants to acclimate themselves to the instrumentation and experimentally constrained run-up. Following the submaximal kicks, a second upright standing trial was collected. Next, the participant completed a series of 10 maximal effort instep kicks of a stationary soccer ball with the standardized 3-step run-up. At least 1-minute of rest was given between trials. A third upright standing trial was collected immediately after the first set of maximal effort kicks.

For the intervention, the participant was asked to lay on their side on a chiropractic treatment table. The investigator (AP) performed a maximum of 3 high-velocity low-amplitude procedures directed to either the participant's pelvis or lumbar spine with an intent to produce cavitation. No additional procedures were performed if cavitation occurred on either the first or second attempts. An inability to produce cavitation does not indicate ineffectiveness of the treatment, according to previous literature[18]. The individual markers were then replaced over the previously marked anatomical locations. A fourth upright standing trial was collected immediately after. The individual markers were then removed again prior to the participant completing a second series of 10 maximal effort instep kicks with the same standardized 3-step run-up. A fifth and final upright standing trial was collected following the second set of maximal effort kicks.

After the final upright standing trial, a second interview was conducted. Questions for this interview focused on the athlete's perception of whether the intervention affected their ability to kick (Appendix A). Feedback was also solicited from the participant at the end of the protocol

about positive and negative aspects of the study. After this interview, the remaining instrumentation was removed and the participant was dismissed.

Instrumentation

Kinematic data was acquired from the lower extremities, pelvis and thorax using a 10-camera optoelectronic motion capture system (Vero 2.2, Vicon Motion Systems Inc., Centennial, CO, USA). The setup of instrumentation was similar to previous studies conducted within the same lab[19,20]. Markers were stuck to the ball's exterior surface to monitor its position prior to impact and post-impact movement. All kinematic data were recorded at a rate of 240Hz. Kinetic data were also recorded from two ground-embedded force plates (AMTI Inc., Watertown, MA, USA). The ball was placed on one force plate with the other force plate providing the landing surface for the participant's stance limb during kicking trials. These data were synchronously collected with the kinematic data at a rate of 2,400Hz (Lab Lock, Vicon Motion Systems Inc., Centennial, CO, USA).

Data Processing

Digital recordings of the interview audio were transcribed verbatim. Accuracy was ensured by reviewing completed transcripts with audio recordings. Each participant received a copy of their transcript to review and ensure representativeness of responses. Participants were able to recommend revisions to the transcript.

The development of the anatomical model was derived from a previous kinematic investigation carried out by Howarth et al[20]. All kinematic and kinetic information were imported into Visual3D (Germantown, MD, USA) for post-data-collection processing, as illustrated in Figure 2. To establish a participant-specific model of the lower extremities (feet, shanks, femurs), pelvis, and thorax, kinematic data from the upright standing trial were employed.

Anatomical reference frames for each segment were established based on digitized anatomical landmarks, effectively determining the neutral posture for all joints within the model. Throughout all kicking trials, the movement of each segment was tracked using the motion capture system.

Virtual markers, including the tibial tubercles, iliac crest (of the kicking leg), 12th rib (of the kicking leg), xiphoid process, and suprasternal notch, were incorporated into the model's construction. These virtual markers were monitored across all trials using rigid body transformations and data obtained from markers affixed to the rigid plastic plate located on the corresponding segment (e.g., shanks for tibial tubercles, pelvis for iliac crest, thorax for 12th rib, suprasternal notch, and xiphoid process).

The event of foot-ball impact was determined by the first instant of movement for any of the markers affixed to the ball. Ball velocity was determined directly using 3D coordinate data from the markers that were fixed onto the ball. The kicking cycle initiated at kicking foot toe-off and concluded at kicking foot toe inflection[21].

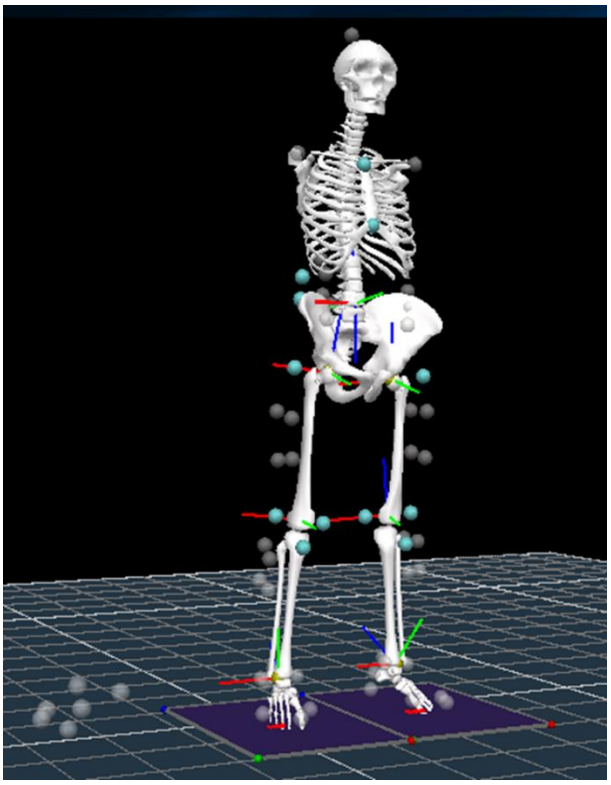

Figure 2 – The Visual3D Professional™ representation of a participant.

Analyses

Analysis was focused on measures of feasibility related to the availability of kinematic data. A gap in the kinematic data was defined as a missing frame during the motion capture. One kinematic frame has a time length of ~0.004 seconds (1/240). The primary measurement of feasibility was the percentage of all participants with no gaps for segment tracking greater than 5 consecutive frames (~0.021 seconds) from start to end of the kicking cycle in at least 70% of all kicking trials. A threshold of at least 90% of participants was used to determine feasibility. Another quantitative indicator of feasibility was the time from end of treatment to the first post-treatment kicking trial. The distance between the virtual and physical makers for the tibial tubercles, iliac crest (kicking leg), 12th rib (kicking leg), xiphoid process and suprasternal notch were also calculated. This primarily assessed for movement of the rigid plastic plates from either the kicking trials or the treatment. If there was no shifting of the rigid plates on the skin, then the virtual and actual markers would have a distance between them of almost zero. For reference, the marker diameter was 14mm.

Comments and feedback regarding the protocol and personal experiences from the athletes were reviewed and synthesized. Data from the interviews were separately coded for important themes by two investigators. Investigators met thereafter to discuss agreements/disagreements in order to come to consensus.

RESULTS

Participant Demographics

A total of 12 participants were recruited through convenience sampling over a span of 3 months. Ten participants were male while 2 were female. The average age, mass, and height of

the participants were as follows: 24 (± 3) years, 76 (± 8) kg, and 179 (± 8) cm. Playing positions included 1 goalkeeper, 1 centreback, 3 fullbacks, 4 centre midfielders, 1 winger, 1 attacking midfielder, and 1 striker. Ten of the twelve participants were right-footed. Lumbar assessment findings were as follows: 6 participants had spinal segmental restrictions at the right L3-4 level, 4 participants had spinal segmental restrictions at the right L4-5 level, and 2 participants had spinal segmental restrictions at the left L3-4 level. The "lumbar pull" technique was used for all interventions.

Analysis of Kinematic Data Gaps

In total, the number of kinematic data gaps obtained during data collection was 489. Of these, 158 gaps were deemed unfillable as the gaps exceeded the maximum interpolation window of 5 consecutive frames in length. Out of 158 unfillable data gaps, 145 were found to have been due to investigator error, while only 13 gaps were due to non-investigator error (Figure 3). Of the total 12 participants, two (Subject 5 and 9) failed the feasibility criterion of achieving greater than 70% of usable kinematic data from all kicking trials (Table 1).

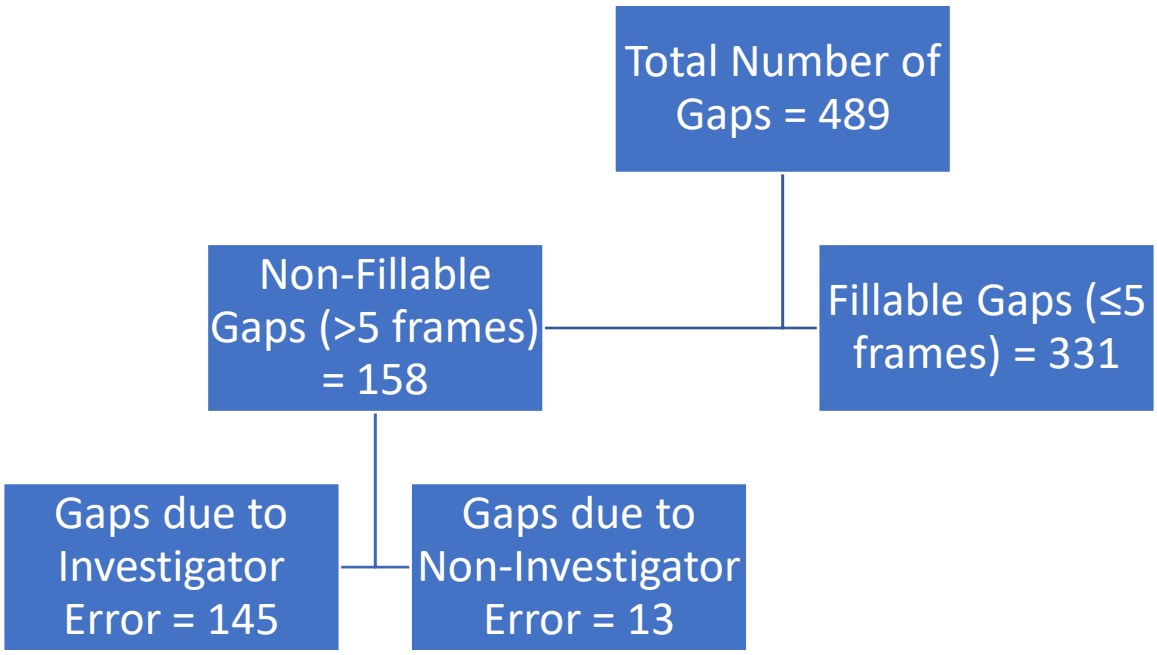

Figure 3 – Analysis of kinematic data gaps

Participant	Set 1 (/10)	Set 2 (/10)	Total (/20)	Participant	Set 1 (/10)	Set 2 (/10)	Total (/20)
S01	1	1	2	S07	0	1	1
S02	0	0	0	S08	1	0	0
S03	0	1	1	**S09**	2	**10**	12
S04	2	2	4	S10	0	1	1
S05	**10**	**10**	20	S11	0	0	0
S06	0	0	0	S12	0	0	0

Table 1 - Summary of unusable trials by participants. Participants highlighted in bold red font are those that failed the criterion of at least 70% of kicking trials with complete usable kinematic data. These were the result of investigator error.

Distribution of Data Gaps

The distribution of data gaps is illustrated in Figure 4. There were four important takeaways from this analysis. The first was that most of the gaps (88%) were only 1 or 2 frames in length (demonstrated by the blue and orange coloured segments of the bars). Secondly, gaps for the whole cycle were the result of investigator error. Thirdly, many segments had no gaps that were unrelated to investigator error (e.g., kicking shank). And finally, the kicking foot was found to be the segment with the most gaps (43% of gaps not related to investigator error).

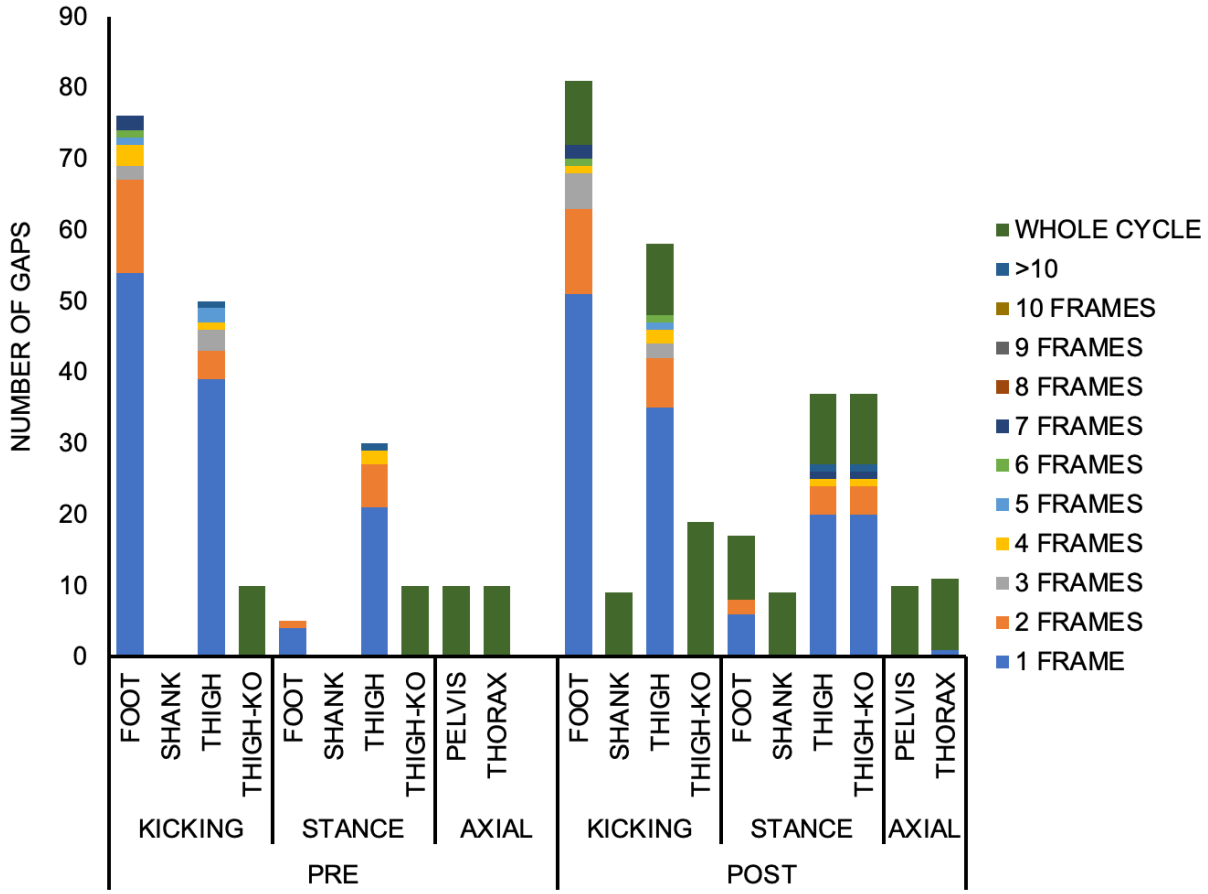

Figure 4 – Distribution of data gaps

Separation Distance Between Virtual and Physical Markers

Figure 5 demonstrates the separation distance between virtual markers and physical markers that remained on the participant throughout data collection. The smallest difference between physical and virtual marker locations was for the tibial tubercles. Larger differences were observed for the xiphoid process and suprasternal notch. All separation distances were within the diameter of a marker (14 mm). Another important observation is in regard to the the gold and black bars. The gold and black bars compare two different models applied to the same upright standing trial that was collected after the second set of maximum kicks. Recalibrating the anatomical model after the treatment reduced the differences between physical and virtual markers.

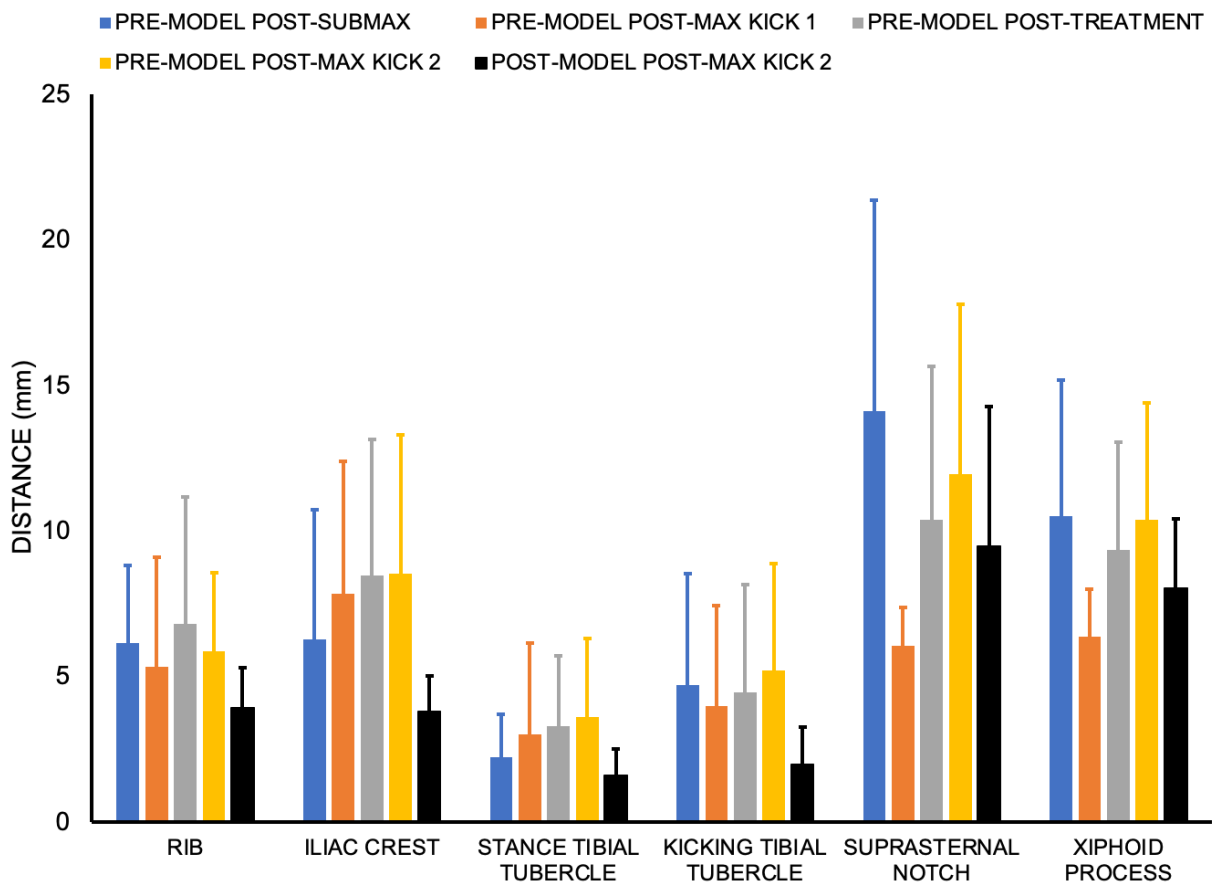

Figure 5 - Separation distance between virtual and physical markers

Duration of Treatment and Calibration

Table 2 demonstrates the time durations from the end of the ten pre-intervention maximal effort kicks to the beginning of the ten post-intervention maximal effort kicks. The time to perform treatment and collect the post-treatment upright standing trial took an average of 4 minutes and 19 seconds, with a minimum of 3 minutes 2 seconds and maximum of 5 minutes 32 seconds. The duration from the start of treatment to the first post-treatment kicking trial took an average of 6 minutes and 35 seconds, with a minimum of 4 minutes 15 seconds and maximum of 8 minutes 51 seconds.

Subject	End of 10 Pre-Intervention Maximal Effort Kicks	End of Post-treatment upright standing trial	Beginning of 10 Post-Intervention Maximal Effort Kicks	DURATION	
S01	13:49:06	13:53:56	13:56:24	00:04:50	00:07:18
S02	15:30:25	15:35:57	15:39:15	00:05:32	00:08:50
S03	18:01:10	18:05:24	18:08:18	00:04:14	00:07:08
S04	17:23:22	17:27:04	17:29:45	00:03:42	00:06:23
S05	17:12:27	17:15:29	17:16:42	00:03:02	00:04:15
S06	17:15:24	17:19:41	17:21:28	00:04:17	00:06:04
S07	18:36:14	18:41:00	18:42:42	00:04:46	00:06:28
S08	15:03:41	15:07:36	15:09:00	00:03:55	00:05:19
S09	16:32:41	16:37:09	16:38:56	00:04:28	00:06:15
S10	12:37:42	12:41:24	12:43:17	00:03:42	00:05:35
S11	14:14:06	14:19:21	14:22:57	00:05:15	00:08:51
S12	16:55:09	16:59:15	17:01:43	00:04:06	00:06:34
		AVERAGE		00:04:19	00:06:35
		MIN		00:03:02	00:04:15
		MAX		00:05:32	00:08:51

Table 2 – Duration of treatment and calibration

Ball Speed and Kicking Cycle Duration

The average pre-intervention kicking speed was 23.4 m/s (± 1.9). The average post-intervention kicking speed was 23.5 m/s (± 2). The average pre-intervention kicking cycle duration was 500 ms (± 41). The average post-intervention kicking cycle duration was 480 ms (± 45).

Qualitative Data – Previous Experiences of SMT, Definition of Performance, and Expectations of the Intervention on Kicking

Of 12 participants, 7 participants reported having limited experiences of manipulation in their career. Ten participants reported having had chiropractic care in their careers. When describing how they felt after receiving care during their athletic careers, all ten participants reported a common theme of "relieving tension and tightness" in the body. Some phrases used to further describe this common theme were as follows: "feeling loose", "feeling free", "increasing range of motion", and feeling a "release". When asked why or when they would seek care, 10 participants reported seeking care when "injured or feeling stiff/tight/sore". Five participants also reported seeking care for "maintenance purposes" as well as "enhancing the longevity of their careers".

When defining "performance", 10 participants reported a common theme of "feeling optimal". When further probed, participants felt that performance meant "playing to the best of my ability", "feeling 100%", "achieving my body's maximum potential", and "being free of any unpleasant sensations" including "soreness, fatigue, cramps, pain, stiffness, and injury". All 12 participants mentioned physical attributes as being an important part of performance. Of these physical attributes, 8 participants mentioned "power and strength", 6 mentioned "agility and technique", 4 mentioned "speed and reaction", and 8 participants mentioned "endurance". Nine

participants alluded to mental attributes as also being an important part of performance, including “focus”, “concentration”, “belief”, and “confidence”.

Of 12 participants, 7 reported being unsure of their expectations with manipulation on instep soccer kicking. The other 5 participants hypothesized that the intervention of manipulation may increase their range of motion as well as the force generated to kick the ball.

Qualitative Data – Experiences of Interventional Effects

Of 12 participants, 9 participants reported feeling relief in the low back in the post-interventional kicks (although all subjects were screened for pre-existing low back pain). Seven participants reported perceiving greater force production in the post-intervention kicks. Nine reported perceiving greater low back and hip range of motion during the post-intervention kicks. Three participants reported perceiving greater efficiency and “smoothness” of movement during the post-intervention kicks. A total of three participants reported minimal or no difference after intervention.

Qualitative Data – Experiences of Study Design

Of 12 participants, 11 participants reported no interference of instrumentation during the trials. The 1 participant that experienced interference of the instrumentation reported “trying not to knock the instrumentation off”. Nine participants reported no effect of the ‘dead time’ on the body. The other 3 participants felt that they may have “cooled down” during the waiting periods involving instrumentation and calibration. Ten participants reported that the number of trials were just right. The other 2 reported that the number of kicks was “slightly too many”. Six participants would not change the experimental protocol, however 4 participants recommended a more realistic surface for kicking (such as grass or artificial turf), and 2 participants

recommended a more diverse warm-up, including more “activation work” and more “multi-joint movements”. No major adverse events were reported by the subjects.

DISCUSSION

The primary purpose of this study was to determine the feasibility of conducting a larger, controlled trial examining the effect of SM on BV during an instep kick. Studying whether biophysical function is changed post-SMT is an interest for both clinical and sport-focused researchers alike. Without including investigator error, this study was able to demonstrate feasibility by achieving at least 90% of participants having greater than 70% complete kinematic data. Investigator error can include issues such as clearly labeling all markers on the participant. The data demonstrate that acquiring kinematic data from participants performing a complex athletic task in a pre-post SMT intervention study is feasible. Qualitative feedback from our participants also support this conclusion. Findings from this study can be used to inform methodology of future clinical/performance studies.

A major limitation in previous studies[11] that aimed to collect kinematic data was the inadequacy of the motion capture system. Previously, other motion capture system models were unable to capture the multiplanar aspect of the instep kick[11]. One major challenge that arose from a previous trial in collecting kinematic data included the need to have markers connected by wires and to have the participant tethered to the data acquisition controller[11].

Our study was able to enhance the motion capture methodology, through aspects such as increasing the number of cameras (10 cameras), to provide important insight into kinematic changes during the instep kick. Although our main objective was that of feasibility, participants’

qualitative responses on how they felt during the motion of the kick may also be compared to their respective quantitative kinematic data in future studies.

The data relating to the separation distances between the physical and virtual marker locations was encouraging. We suggest that the separation distance was predominately from shifting of the rigid plastic plates that were used to track segmental kinematics. The largest distance was seen for the markers that were further from the rigid plastic plates. For example, the virtual position for the suprasternal notch was reconstructed using the markers on the plastic plate at the thoracolumbar junction. By contrast, the 12^{th} rib and xiphoid process were also reconstructed using the markers on the plastic plate at the thoracolumbar junction. The distance from the thoracolumbar junction to the suprasternal notch is much larger than the distances from the thoracolumbar junction to either the 12^{th} rib or the xiphoid process. Thus, a small change in the position/orientation of the plastic plate at the thoracolumbar junction will be reflected in greater discrepancies between the physical marker and the reconstructed location of an anatomical landmark that is further away from the plastic plate. What is also apparent is that the distance is smaller for all locations when a separate model is built from a trial collected immediately after the treatment. Therefore, recalibrating the anatomical model after the treatment is demonstrated to reduce the differences between physical and virtual markers in future trials.

Considering the main study objective was to assess feasibility, only a brief discussion of ball speed measurements is included.. On average, there was a difference of 0.1 m/s between pre- and post-intervention kicks. After interviewing our participants, 9 out of 12 reported feeling an enhanced low back and hip range of motion during the kick and 7 of 12 reported perceiving a greater force production in their kicks post-intervention. Due to the nature of this study, we cannot infer any true differences in performance , however qualitative experiential data from our

participants was helpful to understand the perspective of the athletes, and may inform future research. Understanding the subjects were skilled athletes able toeffectively execute the task of striking a soccer ball, this intervention may not have been sufficient to quantitatively demonstrate a difference in ball speed. We were also interested to see the majority of our athletes perceived an enhanced efficiency of movement that perhaps could allow them to continue performing high-level kicks, but with less perceived output. Future larger scale mixed-methods randomized control trials can help to better address these knowledge gaps.

Our findings should be interpreted with caution given the limitations. We had a small sample size, lacked a control group, and had only 2 female participants. Other limitations include an unrealistic kicking surface (we used regular flooring instead of artificial turf or grass) as well as external ball markers that periodically dislodged from the ball due to the forces enacted on it. Future studies should look to include balls with internal GPS tracking to measure ball speeds, eliminating the hassle of external ball markers. In addition, the lack of a control group precludes any conclusions on the causal effects of SMT on ball velocity.

Some strengths related to our study include a successful motion capture system, the level of athletes included, and the number of calibrations performed. We recommend keeping the inclusion criteria to athletes of elite or sub-elite calibre allowing the participant characteristics to remain meanigful to the resultant high performance measures. The number of calibrations performed in this study helped to monitor the amount of movement of the kinematic markers in between important parts of the trial, which were found to be no larger than the diameter of the marker itself.

CONCLUSION

Our study is of practical importance to both health care providers and strength and conditioning professionals working with athletes. Athletes often report immediate improvement in performance post SMT; however, there is still a paucity of empirical evidence characterizing these mechanisms[7]. Our study adds to this evidence gap and highlights the feasibility and appropriateness of conducting a larger study, that is appropriately powered and controlled.

ACKNOWLEDGMENTS

The authors acknowledge the invaluable assistance by research assistants Erinn McCreath-Frangakis and Austin Rees. The authors also recognize the funding support from the Canadian Memorial Chiropractic College and the Royal College of Chiropractic Sport Sciences (Canada).

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Appendix A – Interview Guide

To the athlete/participant before instrumentation

1. What is your past experience with chiropractic treatment?
    a. What is your experience with manipulation by any health care practitioner?

2. Can you describe how you define performance?
    a. What does it mean for you to have played a good game? (probe individual performance as opposed to team performance)
    b. Can you measure individual performance?

3. What is your expectation of chiropractic treatment on your performance? Please describe.
    a. Why/When do you seek care?
    b. What is your expectation of manipulation on performance?

To the athlete/participant after post-treatment kicking trials

4. How did the intervention affect your ability to kick? Please describe.

    Probe: How did the intervention affect your ability to move during the soccer kick? If affected, describe it and how it affected/felt on the body? What parts were affected?

    Probe: Speed of movement (biomechanical variable = velocity), freedom of movement (biomechanical variable = range of motion), smoothness of movement ((biomechanical variable = jerk), coordination between segments ((biomechanical variable = discrete/continuous relative phase, timing), movement economy/efficiency (biomechanical variable = mechanical work).

5. Did the instrumentation affect your ability to kick? Please describe.

6. Did the "dead time" during calibration and instrumentation have any affect on your performance?

7. What did you think of the number of trials?

    Probe: Did you get tired from the number of trials? Could you have done more? Did you feel your ability to move changed with more trials?

    3 boxes: 1) Too many 2) Just right 3) Too few

8. Do you have any suggested changes to the experimental setup or protocol?

    Probe: Intake and consent, physical assessment, time for instrumentation, warm-up, transition between intervention and experimental trials (i.e., kicks)