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Improvement in Postural Sway measured by the Kinect One in three asymptomatic athletes undergoing a multi-modal program of chiropractic care: A case series

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Abstract: The purpose of this study is to describe the improvements in postural sway measured by the Kinect One in three asymptomatic amateur athletes undergoing a multi-modal program of chiropractic care. An ice skater, a folkloric dancer, and a marathon runner presented themselves to a chiropractic office seeking care at different dates. They each received 12 visits of a multimodal program of chiropractic care and were evaluated pre and post with the Xbox Kinect One depth sensor with a postural sway protocol utilizing the software Medidor-One. Different improvements were observed in postural sway in all subjects, specifically: Patient A improved in all conditions and measurements except in sagittal sway and root mean squared of sway during the eyes closed on the mat condition; Patient B improved in all conditions and measurements; and Patient C improved in coronal sway during the eyes open floor condition, root mean squared of sway during the eyes open on the floor condition, coronal sway during the eyes open on mat condition, and all measurements during the eyes closed on mat condition. Other subjective improvements were also observed. The results from this case series show that a multi-modal program of chiropractic care can improve certain postural sway parameters in asymptomatic amateur athletes, denoting a potential sensory-motor improvement in the athletes. More research with a more robust design is necessary at this time to establish a cause-and-effect relationship between chiropractic care and postural sway improvement.

Indexing Terms: Biomechanics, chiropractic, vertebral subluxation, postural sway.

Introduction

The ability to maintain an optimal balance is essential to human beings today. In the USA direct medical cost related to falls in the year 2015 totalled 31.3 billion dollars for non-fatal falls and $637.5 million for fatal falls with females having a higher propensity to falling. (Burns et al., 2016) The central nervous system (CNS) controls all the sensory information from every system of the body for the proper regulation of motor output and postural maintenance; this is known as postural control. (Ivanenko & Gurfinkel, 2018) In the process of postural control and balance three main sensory systems are engaged; the visual, vestibular, and somatosensory systems. (Alcock et al., 2018) In different sports, balance is a key component of

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successful performance and injury prevention. (Hrysomallis, 2007) A recent increase in the utilization of sports training methodologies that include balance training has been observed, yet questions remain about the proper prescription of these strategies to make a tangible difference in the athlete's performance and injury risk reduction. (Brachman et al., 2017)

Chiropractic care can have a positive effect on balance through improvements in the proprioceptive system, (Haavik & Murphy, 2011; Learman et al., 2009; Rogers, 1997) but limited research exists in this subject. (Holt et al., 2012) In older adults, chiropractic care was able to improve sensorimotor function and multisensory integration related to the maintenance of balance. (Holt et al., 2016) Furthermore, chiropractic care might also have a positive effect on balance by improving different infra and supra pelvic parameters evaluated by radiographic analysis. (Haddas et al., 2020) This is important since chiropractic services to athletic populations have increased in recent years. During the 2013 world games in Colombia, 537 of the 2,964 accredited athletes sought chiropractic care for multiple conditions, and 86.9% reported immediate improvement after receiving chiropractic care. (Nook et al., 2016) Furthermore, nearly 50% of chiropractors who answered a research survey as part of the Australian Chiropractic Research Network reported that they frequently cared for athletes in their clinics or at sporting events. (Adams et al., 2018)

The Xbox Kinect One depth camera (Image 1) has great potential as a tool to analyze different aspects of human movement. Yet, not many investigations related to balance and postural sway are found in the literature. Affordability, portability, and the fact that it is a marker-less system (which makes it easy to use) are the main qualities that attract researchers to use the Kinect. Some research suggests that the Kinect is comparable to high-end optoelectronic cameras like Vicon and Qualisys, (Clark et al., 2012) but more research is necessary on the subject. The purpose of this paper is to discuss the positive changes observed in postural sway parameters measured with the Xbox Kinect One depth camera in three asymptomatic amateur athletes receiving chiropractic care.

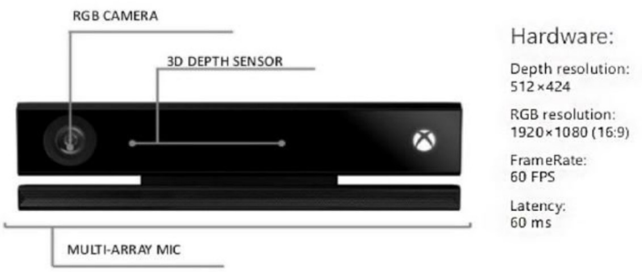


Image 1: Xbox Kinect One camera

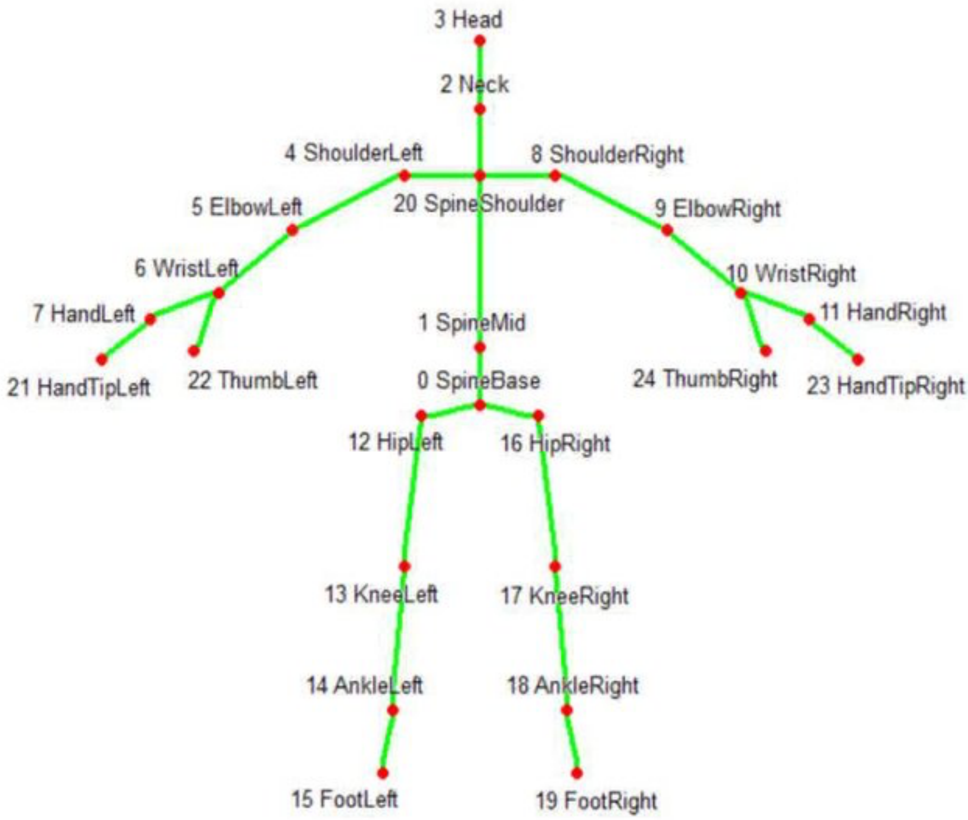
Case report

Three asymptomatic amateur athletes (ice skater, dancer, and marathon runner) presented themselves to a chiropractic office seeking care with different goals in mind. Patient A and B were husband and wife, and because of that came to the clinic within the same time frame. Patient C came in a different timeline as he was not related to the others. All three patients received a thorough consultation to discuss health complaints and goals of care and a complete chiropractic evaluation which included: range of motion evaluation, posture examination, postural sway evaluation using the Kinect depth sensor, and full spine radiographic analysis. Informed consent was obtained from every patient before the submission of this manuscript.

To determine postural sway, a protocol to calculate the center of mass (CoM) previously described in the literature by Leigthley et al. (2017) was utilized. This method calculates the Euclidean mean of three Kinect joints: 'hip left', 'hip right', and 'spine mid' (Image 2). These joints have been shown to be well-tracked by the camera, which makes them ideal for CoM calculation.

Postural sway parameters were calculated by quantifying the following measurements: total sway (TS), coronal sway (CS), sagittal sway (SS), and the root mean squared of the sway (SRMS). The postural sway evaluation was performed with a modified Romberg's protocol (Images 3, 4). Four different conditions were evaluated: 1) eyes open on the floor (EOF), 2) eyes closed on the floor (ECF), 3) eyes open on a perturbation mat (EOM) and, 4) eyes closed on the perturbation mat (ECM). Each condition was evaluated for thirty seconds, with the Kinect sensor placed 3 meters behind the patient. The radiographic analysis utilized a combination of methods of biomechanical analysis for spinal subluxation/displacement; the Pettibon method (Jackson et al., 2000), and the Harrison method. (Harrison et al., 2000; Harrison et al., 2002)

Image 2: Xbox Kinect One 'Kinect Joints'



Images 3 and 4: Placement of the patients for Postural Sway Evaluation

A summary of the findings concerning all three patients is now presented.

Patient A

A 22-year-old Hispanic male amateur ice skater presented himself to the clinic on September 12th, 2019 seeking chiropractic care (see Table #1 for body composition). He was a recent college graduate and his goals for care were to improve his athletic performance and prevent injuries. The patient stated that for the past year he had been going to a chiropractor where he previously lived and received '*general manual adjustments*' (as described by the patient) on a one to two times per month basis. At that time, he did not receive radiographic evaluation and mentioned that the chiropractor relied on '*palpation to find movement restrictions*'. Physical evaluation revealed normal range of motion (ROM), visual postural analysis displayed a right high shoulder and anterior head translation, and a high right hip. Radiographic findings are observed in Table #2, and postural sway findings are noted in Table #3. The review of systems was unremarkable, and there were no other health concerns presented by the patient.

Table 1: Body compositions

	Patient A	Patient B	Patient C
Height (cm)	172	167	175
Body Mass (kg)	78	54	68
BMI	26.4	19.4	22.2

Table 2: Patient A Radiographic findings

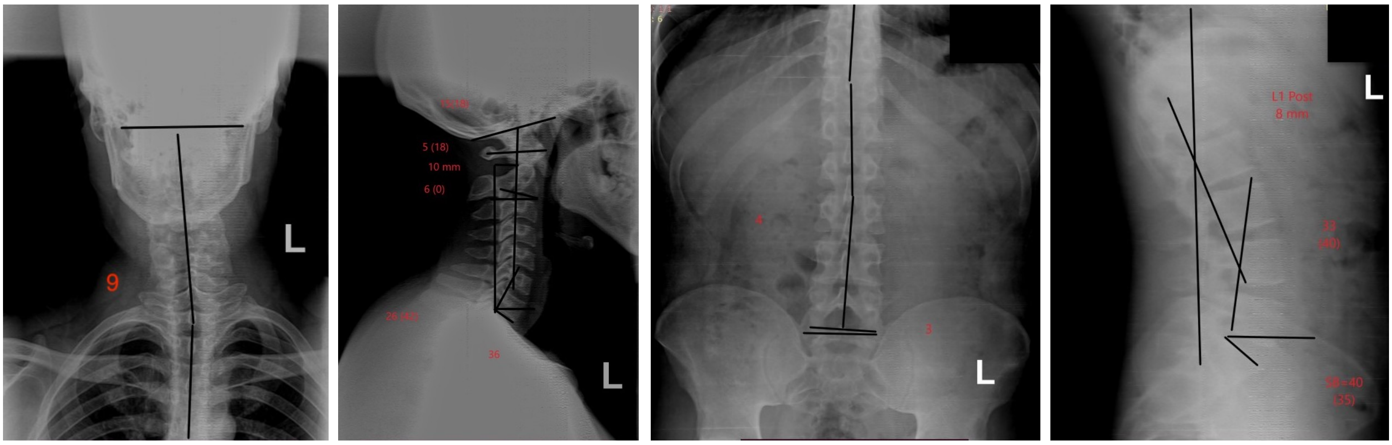


Table 3: Patient A Postural Sway findings

	TS-EOF	CS-EOF	SS-EOF	S-RMS EOF	TS-ECF	CS-ECF	SS-ECF	S-RMS ECF	TS-EOM	CS-EOM	SS-EOM	S-RMS EOM	TS-ECM	CS-ECM	SS-ECM	S-RMS ECM
Pre	1.25 cm²	1.66 cm	.96 cm	.46 cm	10.49 cm²	4.42 cm	3.02 cm	1.39 cm	3.79 cm²	2.77 cm	1.74 cm	.82 cm	26.39 cm²	7.14 cm	4.7 cm	1.78 cm
Post	.83 cm²	1.13 cm	.93 cm	.39 cm	7.24 cm²	3.74 cm	2.47 cm	1.02 cm	2.3 cm²	2.09 cm	1.4 cm	.57 cm	25.22 cm²	5.95 cm	5.39 cm	1.87 cm

Patient B

A 23-year-old Hispanic female competitive folkloric dancer presented herself to the clinic on September 12th, 2019 seeking chiropractic care (see Table #1 for body composition). She had recently graduated from college and her main goal of care was injury prevention. Like her husband, for the past year, she had been going to a chiropractor and received '*general manual adjustments*' (as described by the patient) on a one to two times per month basis. She did not receive radiographic evaluation as her chiropractor relied on '*palpation to find movement restrictions*'.

Physical evaluation revealed normal ROM. Visual postural analysis displayed right lateral flexion of the head, a high left shoulder, and anterior head translation. Radiographic findings in our clinic are given in Table #4, and postural sway findings are noted in Table #5. During the review of systems, the patient mentioned that she had very painful menses and had been diagnosed 4 years ago with dysmenorrhea. For this condition, she ingested 400 mg of Ibuprofen every four hours for at least two days of her monthly cycle. There were no other health concerns presented by the patient.

Table 4: Patient B Radiographic findings

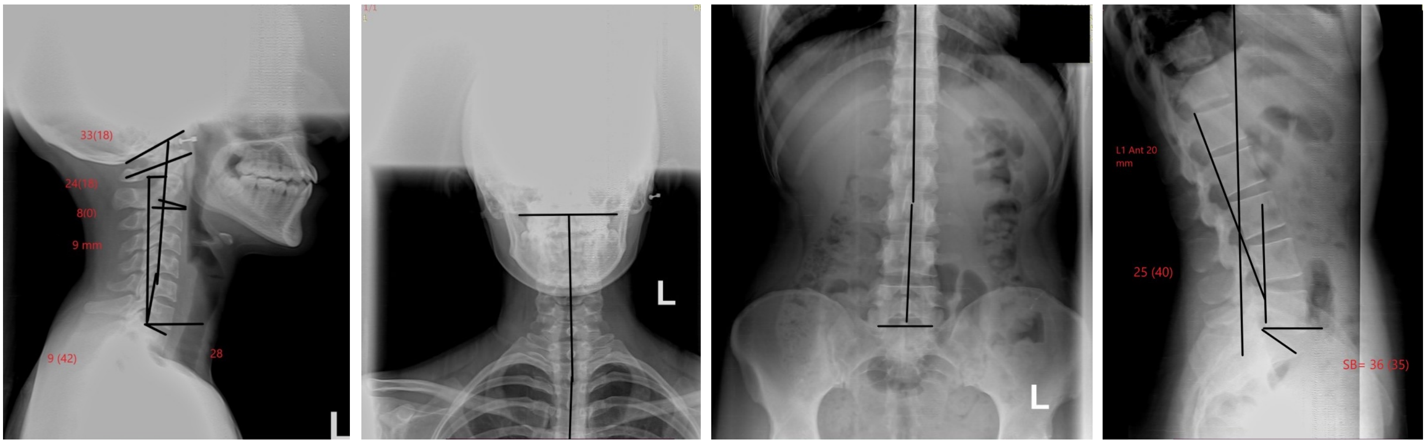


Table 5: Patient B Postural Sway findings

	TS-EOF	CS-EOF	SS-EOF	S-RMS EOF	TS-ECF	CS-ECF	SS-ECF	S-RMS ECF	TS-EOM	CS-EOM	SS-EOM	S-RMS EOM	TS-ECM	CS-ECM	SS-ECM	S-RMS ECM
Pre	4.12 cm²	1.78 cm	2.94 cm	.94 cm	7.09 cm²	2.54 cm	3.55 cm	1.14 cm	9. 39 cm²	3.08 cm	3.88 cm	.89 cm	22.06 cm²	5.59 cm	5.03 cm	1.46 cm
Post	.85 cm²	1.23 cm	.88 cm	.31 cm	3.93 cm2	1.85 cm	2.71 cm	.73 cm	1.25 cm²	1.56 cm	1.02 cm	.51 cm	11.94 cm²	3.31 cm	4.59 cm	1.23 cm

Patient C

A 50-year-old Hispanic male amateur marathon runner presented himself to the clinic on February 12th, 2020 seeking chiropractic care (see Table #1 for body composition). He was an office worker and the main he had in mind was to prevent the re-occurrence of old running injuries in his low back and lower extremity and improve his posture when running.

The patient stated that he had previously visited a chiropractor sporadically, 1 to 2 times per year. Physical evaluation revealed a reduced ROM in cervical extension. Visual postural analysis displayed right lateral flexion of the head, a high left shoulder, and a high left hip. Radiographic findings are observed in Table #6, and postural sway findings are noted in Table #7. The review of systems was unremarkable, and there were no other health concerns presented by the patient.

Table 6: Patient C Radiographic findings

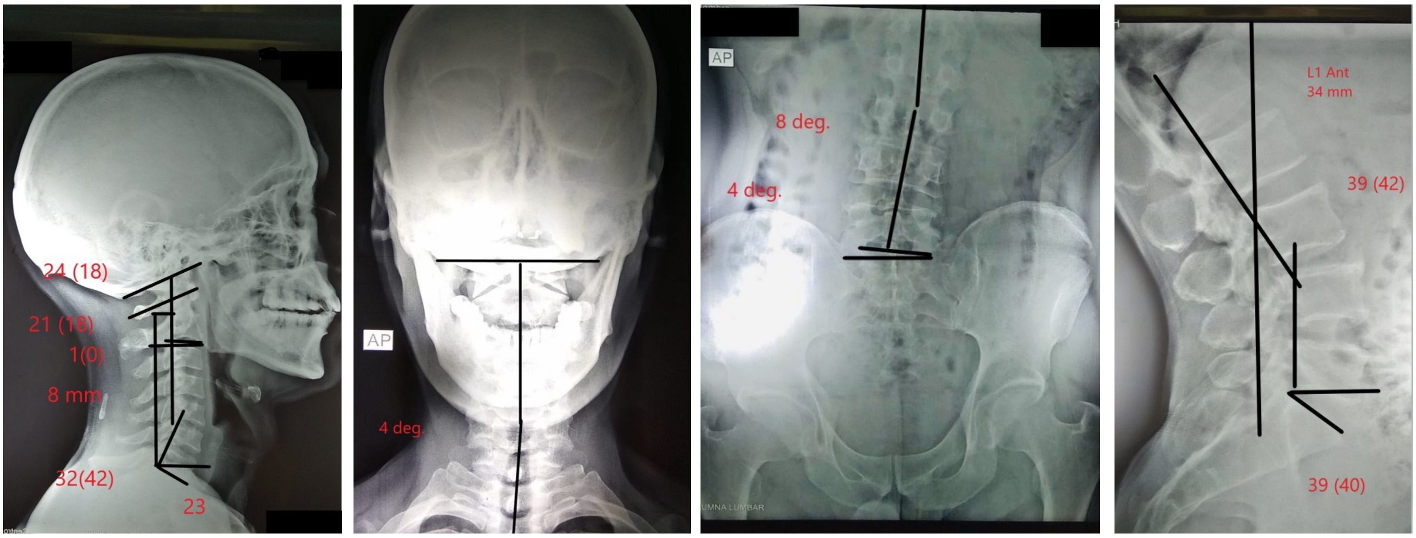


Table 7: Patient C Postural Sway findings

	TS-EOF	CS-EOF	SS-EOF	S-RMS EOF	TS-ECF	CS-ECF	SS-ECF	S-RMS ECF	TS-EOM	CS-EOM	SS-EOM	S-RMS EOM	TS-ECM	CS-ECM	SS-ECM	S-RMS ECM
Pre	.47 cm²	1.37 cm	.43 cm	.44 cm	2.49 cm²	2.3 cm	1.38 cm	.64 cm	1 cm²	1.03 cm	1.23 cm	.46 cm	29.37 cm²	7.64 cm	4.89 cm	1.96 cm
Post	.69 cm²	1.14 cm	.77 cm	.3 cm	7.33 cm2	2.92 cm	3.2 cm	.83 cm	2.42 cm²	2.74 cm	1.12 cm	.57 cm	14.59 cm²	4.03 cm	4.61 cm	1.33 cm

Intervention and Outcomes

All three patients received a multimodal program of chiropractic care. This program incorporates aspects of the Pettibon System of Spinal Biomechanics and Chiropractic Biophysics Technique (CBP®) and the goal of care is the correction of 'global' spinal subluxations (postural) and the improvement of overall sagittal and coronal alignment. (Kent, 1996) The corrective process is considered a multi-modal approach as it includes manual and instrument-assisted chiropractic adjustments (corrections) based on radiographic analysis (see Tables 2, 4, 6), standing repetitive traction also named 'auto-traction', tridimensional wobble seat exercises (3D wobble), and specific use of head and body weights while standing on a whole-body vibration platform (WBV), to induce muscle-reflex activation and achieve an improved spinal alignment.

Certain aspects of this protocol have been previously described in the literature. (Morningstar et al., 2004; Morningstar et al., 2005; Saunders et al., 2003; Morningstar & Jockers, 2009) In these three cases, we included the use of the Denneroll™ Spinal Orthotic (Denneroll Pty Ltd, New South Wales, Australia) a three-point bending traction device, (Moustafa et al., 2017) and the Pro-Lordotic elastic resistance band (Circular Traction Supply Inc., Huntington Beach, CA, USA) which was used to perform Mirror image® cervical extension exercises. (Fortner et al., 2018) Chiropractic adjustments were performed in an Omni drop table and the Arthrostim (IMPAC Inc., Salem, OR, USA) hand-held adjusting instrument was also utilized. Appendices A, B, and C show the components of the corrective process.

For all three patients, spinal adjustments were delivered on a three times per week frequency for four weeks. 'Auto-traction' and wobble seat exercises began with 10 repetitions and increased 5 repetitions per day until reaching the patient's age in repetitions (ie., a 50-year-old person would do 50 repetitions). Head and body weight were performed for 5 to 10 minutes on a WBV platform. Patient A utilized a 4.5 lb. weight, patient B a 4 lb. one, and patient C, 5 lb. Patient A and C also utilized a 10 lb. chest weight for 5 to 10 minutes on the WBV platform. Mirror image® cervical extension exercises with the Pro Lordotic were performed initially for 10 sets holding for 5 seconds and progressing towards 10 sets of 10-second holds. Finally, the Denneroll™ spinal orthotic was utilized progressively beginning with 3 minutes and adding 1 minute per day until reaching 20-30 minutes.

Patient A summary

Patient A received corrective chiropractic care from September 12th, 2019 until October 10th, 2019 for a total of twelve visits. During this time of care in the office and at home protocols were prescribed to the patient. In-office repetitive traction and 3D wobble exercises were performed first, followed by spinal adjustments (using the protocol described above). After the adjustment, specific head weights were placed on the patient while standing on a WBV platform for five minutes. Finally, Mirror image® cervical extension exercises were performed utilizing the Pro-Lordotic elastic band. Home care included daily standing repetitive traction, tridimensional wobble seat exercises, specific use of head weights, and the Denneroll™ Spinal Orthotic three-point bending traction.

At the last visit, a progress evaluation of all exams performed during the initial visit occurred (except x-rays). Improvements in anterior head translation and high right hip were noted on visual postural evaluation. Subjectively, the patient stated that overall he felt better, more relaxed, and able to react quicker on the ice-skating rink. Postural sway parameters improved in all conditions and measurements except during SS and SRMS during the ECM condition (Table #3).

Patient B summary

The patient received corrective chiropractic care from September 12th, 2019 until October 10th, 2019 for a total of twelve visits. During this time of care in the office and at home protocols were prescribed to the patient. In-office repetitive traction and 3D wobble exercises were performed first, followed by spinal adjustments (using the protocol described above). After the adjustment, specific head weights were placed on the patient while standing on a WBV platform for five minutes. Finally, Mirror image® cervical extension exercises were performed utilizing the Pro-Lordotic elastic band.

Home care included daily standing repetitive traction, tridimensional wobble seat exercises, specific use of head weights, and the Denneroll™ Spinal Orthotic three-point bending traction. At the last visit, a progress evaluation of all exams performed during the initial visit occurred (except x-rays). Improvements in right lateral flexion of the head and anterior head translation were observed on visual postural evaluation. The high left shoulder remained present. Subjectively, the patient stated that she felt she had better balance, felt more strength in her lower body, and could sleep better. Importantly, she stated that for the first time in 5 years she did not need to take Ibuprofen for her painful menstrual cycle, as the pain had diminished by 90%. Postural sway parameters improved in all conditions and measurements (Table #5).

Patient C summary

Patient C received corrective chiropractic care from February 12th, 2019 until March 11th, 2020 for a total of twelve visits. During this time of care in the office and at home, protocols were prescribed to the patient. In-office repetitive traction and 3D wobble exercises were performed first, followed by spinal adjustments (using the protocol described above). After the adjustment, specific head weights were placed on the patient while standing on a WBV platform for five minutes. Finally, Mirror image® cervical extension exercises were performed utilizing the Pro-Lordotic elastic band. Home care included daily standing repetitive traction, tridimensional wobble seat exercises, specific use of head weights, and the Denneroll™ Spinal Orthotic three-point bending traction.

At the last visit, a progress evaluation of all exams performed during the initial visit occurred (except x-rays). Improvements in cervical extension ROM were noted, as were improvements in postural distortions namely: high left shoulder and high left hip. The patient's head right lateral flexion remained the same. Subjectively, the patient stated that overall he had more energy, felt more relaxed, was able to maintain a better posture while running long distances, and no re-occurrences of old injuries had occurred during the 4-week time frame. Postural sway parameters improved in CS during the EOF, SRMS during the EOF, CS during the EOM, and all measurements during the ECM condition (Table #7). Of interest is the fact that a worsening was observed in TS and SS in the EOF condition, in TS, CS, SS, and S-RMS in the ECF condition, and TS, CS, and S-RMS in the EOM condition.

Discussion

The purpose of this paper was to document the positive changes observed in postural sway parameters measured with the Xbox Kinect One depth camera in three asymptomatic amateur athletes receiving a multimodal program of chiropractic care. The use of the Kinect is a very practical and easy way to assess postural sway in the clinical setting, especially due to its cost-effectiveness and ease of use. (Lim et al., 2015; Liu et al., 2020) Postural sway evaluation in the clinic is very important as it can be used as an objective measure of the patient's sensory-motor function and overall health. (Tuunainen et al., 2013)

Postural control necessitates the regulation of body position in space for both stability and orientation. (Shumway-Cook & Woollacott, 2007) The CoM is considered by experts to be the main variable being regulated by the nervous system in postural control. Scholz et al. (2007) described the use of a novel analysis tool known as the uncontrolled manifold (UCM) and found that when subjects were recovering from a balance perturbation the re-establishment of the CoM preceded joint positioning. This is evidence that the CoM is the main variable in the maintenance of balance.

As previously stated, somatosensory, visual, and vestibular system integration is key in the process of postural control (Alcock, 2018) and alterations of sway during different conditions could lead the clinician to find which sensory system is at fault. For example, when performing a

Romberg's test and evaluating the condition of EC versus EO, if the sway is larger with the eyes closed this could indicate alterations in the somatosensory system. Furthermore, EC conditions in a perturbation mat can yield information about the vestibular system since the visual field is eliminated. (Hong et al., 2015) This might give a clue of why patient C had, for the most part, improvements in the ECM conditions and had worsened in other parameters. We believe that age plays a role in this since this patient was 50 years of age at the time of the evaluation and intervention. It seems that for this patient the care rendered improved certain aspects of both the vestibular and the somatosensory systems, but not other aspects.

The Kinect depth camera has been investigated for its use in human movement analysis applications including gait, balance, and drop vertical jump, amongst others. (Lim et al., 2015; Guffanti et al., 2020; Gray et al., 2017) Validity and reliability studies have generally found the Kinect to range from modest to excellent in the majority of investigations. (Ma et al., 2019; Latorre et al., 2019; Clark et al., 2012;) The Kinect camera uses infrared light discharged actively to construct a depth image, this application permits the rendition of human movement in three dimensions (3D) with a single camera. (Ye et al., 20011) The sensor can track up to six skeletons at a time and each skeleton has 25 Kinect-joints, (Capecci et al., 2016) and the fact that it is portable, affordable, and does not need calibration to give the Kinect great potential in the assessment of human movement. (Clark et al., 2012) (Image 2)

Recent studies suggest that spinal deformity has a negative effect on postural sway parameters, (Dufvenberg et al., 2018; Godzik et al., 2020) and after surgical correction of the deformity improvements were observed in sway. (Haddas & Lieberman, 2019) Interestingly, spinopelvic alignment seems to be of importance in this subject. In one study Haddas et al. (2020) recruited 44 surgical candidates who suffered from Adult Spinal Deformity (ASD). Patients underwent full-spine radiographic evaluation from both the coronal and sagittal planes to determine alignment. Spinopelvic alignment indicators evaluated were: Cobb angle, central vertical axis live (CVA), the sagittal vertical axis (SVA), pelvic incidence lumbar lordosis (PI-LL), and T1 pelvic angle (T1PA). Romberg's test was utilized to evaluate the functional balance of the subjects. Subjects with greater alterations in spinopelvic parameters were found to have a larger center of mass and head sway during the evaluation. Furthermore, a relationship between spinopelvic alignment measurements and gait parameters was also observed.

Chiropractors must understand the above-mentioned spine and pelvic parameters because many studies have established a correlation between the sagittal balance of the spine as measured in radiographic studies with poor quality of life and worsening of pain syndromes in the lower back. (Glassman et al., 2005; Schroeder et al., 2013) Historically, the main emphasis of chiropractic care has been the location, analysis, and correction of vertebral subluxations (VS). (Rosner, 2016) VS is observed as a displacement or distortion of the spine either at a regional, global or intersegmental level affecting the function of the nervous system. Corrective or postural techniques within chiropractic have an emphasis on the global subluxation and the improvement of sagittal and coronal alignment towards a more normal one. These techniques require radiographic evaluation for proper analysis and x-rays are considered safe to use as a common tool to evaluate spinal alignment. (Oakley et al., 2018; Oakley et al., 2019)

There are certain strengths and limitations related to this case series. First, there were only three patients, and this poses a limitation as no statistical analysis can be performed. The fact that repeat radiographs were not taken to monitor structural changes (this was due to the short amount of time the patients were under care) is considered a limitation as well because we cannot determine if a change in spinal structure was related to improvements in sensory-motor function. Also, all patients were asymptomatic which is not typical of patients seeking chiropractic care, which warrants more research with different symptomatic populations.

Furthermore, the nature of the intervention (multimodal approach) does not allow us to determine which intervention had the largest contribution to improvements in postural sway. Pilot studies are on the way to evaluating the effectiveness of the different interventions above described to improve certain biomechanical and motor control parameters. One key strength of this study is that it was performed in a normal clinical environment (as opposed to a laboratory setting) similar to what any patient would experience in a chiropractic clinic. This is considered a positive because it strengthens the potential for external validity.

Conclusion

The results from this case series reveal that a multi-modal approach of chiropractic care can improve certain postural sway parameters in asymptomatic amateur athletes, denoting a potential sensory-motor improvement in the athletes. Furthermore, the use of the Xbox Kinect depth sensor as a tool to measure postural sway could be implemented routinely in chiropractic clinics due to its affordability, portability, and ease of use. More research with different populations is necessary at this time to establish a cause-and-effect relationship between chiropractic care and postural sway improvement.

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Appendices

A - Pre Spinal Adjustment Protocol

B - Post Spinal Adjustment Protocol

C - Example of X-ray Based Spinal Adjustments