The impact of cranial loading on sagittal plane posture, kinanthropometry and muscle activity of South African female youth

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ABSTRACT

Background: Cranial or head-loading porterage is a popular occupation for many adolescent and young women in South Africa and other developing countries, to secure a paltry wage and/or as a compulsory domestic duty, particularly for female youth in rural South African communities. This has raised concerns regarding postural health.

Objectives: To compare the change in sagittal plane postural heights, manual vertebral angular goniometry and muscle activity of cervical and lumbar flexors-extensors between South African female youth when carrying and not carrying cranial loads.

Methods: One hundred young South African female volunteers (aged 9–17 years) participated in an observational randomised controlled study, involving a pre-test/post-test crossover. The experimental group ($n = 50$) stood in a cranial loaded position with their habitual head-load mass (8.0 ± 2.5 kg). Participants' body mass, standing vertex, acromion, anterior sacroiliac spine (ASIS) and navicular heights, craniovertebral angle (CVA), craniohorizontal angle (CHA), standing pelvic angle (SPA), and their cervical and lumbar flexors-extensor electromyographic (EMG) activity were measured. The control group ($n = 50$) was measured without the cranial load. The experimental group crossed over into the control group, and vice versa.

Results: Cranial loading decreased vertex (1.45 ± 0.1 vs 1.44 ± 0.12 m), acromion (1.17 ± 0.11 vs 1.16 ± 0.11 m), ASIS (0.83 ± 0.07 vs 0.82 ± 0.07 m) and navicular heights (0.03 ± 0.2 vs 0.06 ± 0.2 m) compared to unloaded phases ($p < 0.001$). Similarly, CVA (13.7 ± 5.3° vs 19.4 ± 5.8°), CHA (51.9 ± 6.9° vs 54.5 ± 6.6°), and SPA (17.9 ± 7.7° vs 20.5 ± 7.9°) increased during the loaded phase ($p < 0.001$). While the EMG muscle activity of both the cervical (flexors: 3.1 ± 1.9 vs 5.8 ± 3.4 mV and extensors: 4.5 ± 2.6 vs 8.7 ± 4.9 mV) and lumbar (flexors: 3.6 ± 2.4 vs 4.9 ± 3.6 mV and extensors: 5.5 ± 3.5 vs 8.3 ± 4.6 mV) increased during the loaded phase, the extensors were more strongly activated ($p < 0.001$).

Conclusion: Cranial loading changes the sagittal plane posture of female youth by diminishing their height, anteriorly rotating their pelvises, and flattening their feet, potentially causing musculoskeletal problems.

INTRODUCTION

Cranial or head-loading porterage is the physical act of carrying external loads on one's head, which is a popular task allocated to many pubescent, adolescent and young women in India, Nepal, Ghana, Nigeria and South Africa.[1-4] Head porters in these countries typically carry goods in local markets, from wholesalers to sellers, and from sellers to buyers. Many Ghanaian adolescent and adult females leave their rural homes in search of work in the urban centres to work as *kayayo* or head porters carrying heavy cranial loads for a minimal wage.[3] A similar scenario occurs in Nigeria, where adolescent and adult female head-loading porters are referred to as *alabaru*.[4]

Cranial loading is also a common practice assigned to many young African females in rural communities,[1,2] where food, water, and firewood are carried over distances of 10 km or more.[1,2] Head loads have been reported to be as heavy as 35 kg.[2] Female adolescents aged 15 years are capable of carrying a cranial load of 25 kg.[5]

The impact of cranial loading on the development of the adolescent spine has become a worrisome concern of the health fraternity.[6-8] Three empirical investigations have recorded the neuro-musculoskeletal impact of habitual cranial loading on African female porters.[9-11] Only one study was conducted in South Africa, highlighting the paucity of empirical findings.[11]

The existing empirical neuro-musculoskeletal health investigations have revealed that habitual cranial loading causes spondylolisthesis, intervertebral disc compression, and decreased standing vertex height.[9-11] Echarri and Forriol (2002) and Echarri and Forriol (2005) identified intervertebral disc compression and spondylolisthesis among African female adult porters by employing clinical radiography, which requires costly equipment that is scarce in most rural South African communities.[9,10] Affordable but reliable (high external-validated applied research) experimental protocols are required to measure the impact of cranial loading on the posture of head porters.[8]

Ellapen et al. (2009) used manual kinanthropometric measures to identify changes in vertebral posture due to cranial loading.[11] The study described in this paper was an extension of Ellapen et al.'s empirical investigation, and included kinanthropometrical height differential measures, basic manual goniometry and electromyographic (EMG) measures. The aim was to measure the impact of cranial loading on the posture and muscle activity of rural South African head porters.

METHODS

This was an observational randomised control study, involving a pre-test/post-test crossover. All participants were female youth volunteers, aged 9–17 years, who habitually carried head loads, and who resided in the Glendale region of the iLembe district of the province of KwaZulu-Natal. The participants were randomly distributed into experimental (n = 50) and control (n = 50) groups. The control group crossed over into the experimental group approximately two hours later, and vice versa (Figure 1). This allowed both groups to be exposed to the same intervention of carrying their usual head loads. The control was in the unloaded phase without a cranial load, while the experimental group carried the cranial load for a duration of approximately 15 minutes.

Kinanthropometric measurements

Kinanthropometric measurements included body mass and the following heights: standing vertex, acromion, anterior superior iliac spine (ASIS) and navicular heights from 'unloaded' to 'loaded' as per the International Society for Advancement of Kinanthropometry (ISAK) protocol.[12] The cranial loads carried, and participants' body mass were measured on an electronic scale. All measurements were taken on the participants' right sides.

Biomechanical angles

The selected biomechanical angles measured included the craniovertebral angle (CVA), craniohorizontal angle (CHA), and standing pelvic angle (SPA). The CVA and CHA were measured according to the Lau et al. (2009) protocol.[13] The standing pelvic angle (SPA) was measured according to the Kim et al. (2009) protocol.[14]

Electromyographical measures

The cervical and lumbar extensor and flexor anatomical sites were cleaned with alcohol swabs after which EMG electrodes were attached at the belly of the extensor and flexor muscles, respectively. The EMG measurements reflected the changes in voltage during the cranial loading and unloading phases of the cervical and lumbar extensors and flexors, respectively. Lo Martire et al. (2017) reported that surface EMG measures have a reliability score of 0.79.[15] The EMG data were normalised through dynamic maximal forceful cervical and hip flexion and extension, respectively. The maximal cervical flexion trial commenced from an anatomically neutral head position to full flexion, with the chin touching the sternum. Resistance was offered by a thera-band that held the head in a neutral anatomical alignment. Maximal cervical extension was completed to the point of maximal neck extension. Similarly, resistance was offered by a thera-band by holding the head in an anatomically neutral position. Dynamic maximal forceful hip extension was measured when participants held the thera-band with both hands while in a long arc-hip flexion position. The participant stood on the centre of the thera-band with the ends grasped in each hand. When given the command, the participant moved from a long-arch hip flexion position into maximal hip extension. In order to measure maximal voluntary isotonic hip flexion, the participant was required to move from neutral anatomical alignment into maximal hip flexion.

To normalise an EMG signal, the signal obtained during a task was divided by a reference EMG value obtained by measuring the same muscle. This allowed for a relative measure of activation, which is compared to a reference value. A reference value was obtained for the normalisation of EMG recordings by assessing the maximum (peak) activation levels during maximal voluntary isotonic contractions (MVIC).[16,17]

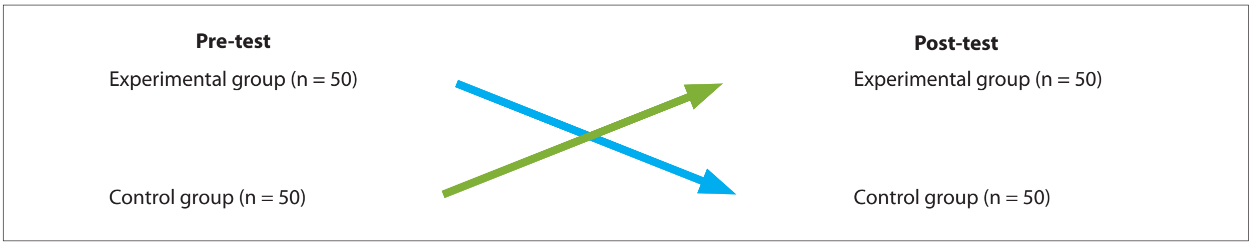
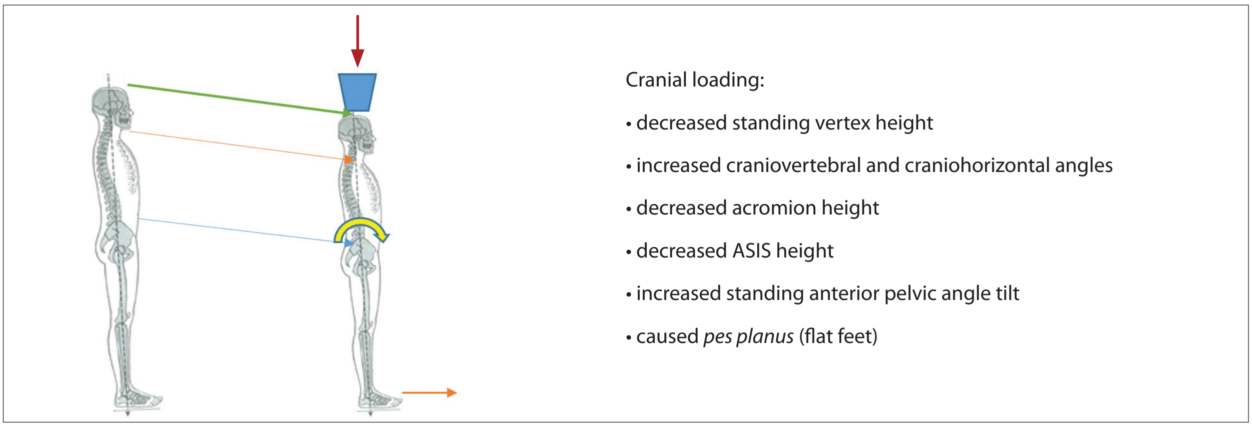


Figure 1. The observational randomised pre-test/post-test crossover design



Cranial loading:

- decreased standing vertex height
- increased craniovertebral and craniohorizontal angles
- decreased acromion height
- decreased ASIS height
- increased standing anterior pelvic angle tilt
- caused *pes planus* (flat feet)

Figure 2. Changes to the musculoskeletal system produced by cranial loading

At least two repetitions of the MVIC were performed to ensure reliability of results. The MyoPlus 4 (Verity Medical, UK) was used to measure muscle voltage changes.

Data analyses

Descriptive analyses included means, standard deviations, and percentage changes in the kinanthropometric measurements, biomechanical angles, and EMG measurements. Changes were assessed using the paired t-test. The unloaded standing vertex, acromion, ASIS and navicular heights' mean scores were compared to the respective cranial loaded differential height mean scores to determine changes in postural heights. Similarly, the average CVA, CHA and SPA unloaded measurements were compared to the respective average cranial loaded measurements to determine changes in postural angles. The mean EMG unloaded cervical and lumbar flexor and extensor scores were compared to their respective loaded cervical and lumbar flexor and extensor scores to determine changes in muscle activity. Significance was set at 95%.

Ethical approval was obtained from the Tshwane University of Technology (REC2020-12-001). Parental informed consent, child assent, and the iLembe Royal ethical consent were granted prior to the commencement of data collection. A member of the iLembe royal staff served as an intermediator and was present during the data collection. The study was conducted in accordance with the Declaration of Helsinki and employed COVID-19 precautionary measures.

RESULTS

The participants were aged from 9 to 17 years (mean 12.3 ± 2.5 years). Mean body index and body mass were 20.5 ± 4.5 kg/m^2 and 44.5 ± 13.7 kg, respectively. The mean cranial load was 17.9% (8.0 ± 2.5 kg) of the mean body mass (percentage cranial load = mean cranial load/mean body mass x 100).

Table 1 shows selected kinanthropometrical heights of participants in the cranial unloaded and loaded phases. Participants' standing vertex, acromion, anterior sacro-iliac spine (ASIS), and navicular heights decreased when the cranial load was imposed on the axial skeleton. Although all heights decreased significantly during the loaded phase, the decrease in navicular height was the most pronounced.

The cranial load produced significant increases in vertebral angles ($p < 0.0001$) (Table 2). The increased CVA and CHA suggest a more erect cervical posture; the increased SPA is suggestive of a greater anterior pelvic rotation (illustrated by figure 2).

The EMG voltage (mV) change showed that cranial loading increased muscle activity ($p < 0.000$) (Table 3). During the unloaded phase, the cervical flexor-extensor percentage ratio was 40.7:59.3, which was similar to the ratio during the cranial loaded phase (40:60). The lumbar flexor-extensor percentage ratio was 39.5:60.5 during the unloaded phase, and 37.1:62.9 during the loaded phase, i.e. there was very little change. The EMG values in Table 3 illustrate that the cervical and lumbar extensor muscles are more strongly activated than the reciprocal antagonist flexors.

Table 1. Kinanthropometrical heights in the cranial unloaded and loaded phases

Kinanthropometrical heights (m)	Unloaded phase (n = 100) Mean ± SD	Loaded phase (n = 100) Mean ± SD	Mean difference* %	p value
Vertex standing height	1.45 ± 0.1	1.44 ± 0.12	-0.6	< 0.000
Acromion height	1.17 ± 0.11	1.16 ± 0.11	-0.8	< 0.000
ASIS height	0.83 ± 0.07	0.82 ± 0.07	-1.2	0.004
Navicular height	0.03 ± 0.2	0.06 ± 0.2	-50.0	< 0.000

* (loaded phase–unloaded)/loaded phase x 100; minus sign (-) indicates decrease

Table 2. Vertebral angular changes in the cranial unloaded and loaded phases (manual goniometry measures)

Vertebral angle (°)	Unloaded phase (n = 100) Mean ± SD	Loaded phase (n = 100) Mean ± SD	Mean difference* (%)	p value
CVA	13.7 ± 5.3	19.4 ± 5.8	+29.3	< 0.000
CHA	51.9 ± 6.9	54.5 ± 6.6	+4.7	< 0.000
SPA	17.9 ± 7.7	20.5 ± 7.9	+12.6	< 0.000

* (loaded phase–unloaded)/loaded phase x 100; plus sign (+) indicates increase

Table 3. Electrical muscle activity changes in the cranial unloaded and loaded phases

Muscle activity (mV)	Unloaded phase (n = 100) Mean ± SD	Loaded phase (n = 100) Mean ± SD	Mean difference* (%)	p value
Cervical flexor	3.1 ± 1.9	5.8 ± 3.4	+46.5	< 0.000
Cervical extensor	4.5 ± 2.6	8.7 ± 4.9	+48.2	< 0.000
Lumbar flexor	3.6 ± 2.4	4.9 ± 3.6	+26.5	< 0.000
Lumbar extensor	5.5 ± 3.5	8.3 ± 4.6	+33.7	< 0.000

*(loaded phase–unloaded)/loaded phase x 100; plus sign (+) indicates increase

DISCUSSION

The main finding from this study was the significant change in vertebral posture of the participants from an unloaded to a loaded position – a finding that concurs with previous literature.[9-11]

Changes in kinanthropometry

The kinanthropometrical findings indicate that cranial loading decreases standing vertex height, as has been reported in previous studies.[10,11] Echarri and Forriol (2005), and Ellapen et al. (2009) reported that cranial loading diminishes cervical vertebral height due to cervical intervertebral disc compression.[10,11] We also showed that cranial loading reduces acromion, ASIS, and navicular heights – novel evidence that the cranial load compresses the intervertebral discs in the thoracic and lumbar vertebrae in the closed-kinetic-chain system. The decrease in the navicular height was the greatest of all changes in heights and suggests that the cranial load flattened the feet (producing *pes planus* or flat feet) by stretching the spring ligament of the foot.

Changes in manual goniometry

Cranial loading increased the CVA, CHA and SPA, which is a novel finding illustrated by figure 2. The increased CVA suggests that the participants adopted a more erect cervical on thoracic vertebral posture, which is contrary to the findings of Echarri and Forriol (2002) and Echarri and Forriol (2005), who reported that cranial loading produces spondylolisthesis – anterior sliding of the superior vertebrae over the inferior vertebrae due to lack of a posterior locking mechanism.[9,10] The anterior translation of the superior cervical vertebrae produces a smaller CVA. It is postulated that the CVA increased in our study because participants habitually adopted a more erect neck posture to balance the cranial load on their heads and reduce the risk of falling. It is possible, however, that the cranial load was not heavy enough to reduce the CVA. It is important to note that participants carried their habitual load masses and not their maximal load masses. The increased CVA reduces the normal anatomical cervical lordotic posture, which produces neuro-musculoskeletal pain. The increase in SPA reflected an anterior rotation of the pelvis – evidence that cranial loading produces greater anterior pelvic rotation, concurring with previous studies.[11] Ellapen et al. (2009) reported that cranial loading does produce greater anterior pelvic rotation and lumbar lordosis (hyperextension of the lower lumbar vertebrae).[11] The increased anterior pelvic rotation produced by the habitual cranial loading has been associated with onset of lower back pain and poor health of head-loading porters.[11,18] The changes in CVA, CHA and SPA are novel findings, but further research is required to validate these findings.

Changes in electrical muscle activity of the cervical and lumbar flexors and extensors

The measurement of lumbar flexor-extensor EMG muscle activity in the loaded and unloaded phases is novel. Cranial loading increased muscle activity in the cervical and lumbar flexors and extensors, from the unloaded phase. These findings suggest that cranial loading over long distances could potentially lead to fatigue of the cervical and lumbar muscles, causing delayed onset of muscle soreness. While the force-couple EMG muscle activity ratio of the cervical and lumbar flexors and extensors remained similar, increased muscle activity was, nevertheless, recorded during the loaded phase. This finding is comparable to that of Shivers (2012) who reported that cranial/head loading increases electrical activity (EMG) in the cervical flexors and extensors in an attempt to support and balance the mass load on the head.[19]

Our findings refute those of Ellapen et al. (2009) who reported increased cervical flexor EMG activity.[11] Even though we recorded an increase in cervical flexor EMG, the cervical extensor EMG activity was stronger. It is postulated that the difference in EMG activity explains the more erect cervical posture.

Head porters are not the only group whose posture is affected by heavy loads. Chen and Mu (2018) reported that children carrying backpacks weighing 15% (and more) of their body mass caused greater anterior pelvic rotation and elicited stronger EMG activity in their lumbar flexors and extensors compared to a lighter load.[18] This supports our finding that load bearing increases lumbar flexor and extensor muscle activity. The stronger loaded lumbar flexor EMG muscle activity supports the finding of increased SPA rotation.

Limitations

We did not measure long-term effects of cranial loading on the postural health of participants, as this was a cross-sectional study.

Recommendations

A longitudinal study should be undertaken to determine the long-term impact of cranial loading on an individual's vertebral column. The effects of different cranial load masses should be measured to ascertain what relative percent body mass of cranial load produces no postural changes. This would reflect the optimal relative cranial percentage mass that can be carried without precipitating deviant posture and neuro-musculoskeletal injury. Youth carrying these cranial loads should be informed of the possible risk of lower back pain. Female head porters should consider wearing a cervical prosthetic brace to combat the abnormal erect cervical posture that they adopt when carrying heavy cranial loads. The cervical prosthetic brace will prevent loss in the normal anatomical cervical lordosis curvature, eliminating neuro-musculoskeletal pain. Similarly, female head porters should wear a lumbar prosthetic brace to reduce the excessive anterior pelvic rotation, thereby reducing the risk of lower back pain.

An alternative and cheaper pragmatic recommendation for head-loading porters is to strengthen their cervical, lumbo-pelvic hip complex and feet muscles. Head-loading porters adopt an erect neck/cervical posture, which reduces the normal cervical lordotic posture – the extreme straightening of the neck, which leads to neck pain. Similarly, head-loading porters adopt an excessively anterior rotated pelvis, which produces hyperextension of the lumbar vertebrae, causing pain. Pelvic stabilisation exercises would strengthen the lower back and hip muscles, preventing excessive anterior rotation. An exercise rehabilitation programme that strengthens ankle and foot muscles is recommended. The increased plantar foot muscle strength will prevent flattening of the feet. Such a home-based rehabilitation programme does not need equipment as it involves simple controlled movements to strengthen muscles, which can be taught by a local community physiotherapist and/or biokineticist.

CONCLUSION

Cranial loading causes changes in vertebral posture and EMG cervical and lumbar muscle activity of female African youth porters. Porters who habitually carry cranial loads adopt a more erect cervical and anterior rotated pelvic posture to support and balance cranial loads. The anterior rotation of the pelvis is a biomechanical change that has been associated with lower back pain.

KEY MESSAGES

1. Cranial loading alters sagittal plane posture, which disrupts the body's normal weight- bearing anatomical strategy, causing cervical and lumbar neuro-musculoskeletal pain.
2. Cranial loading reduces the normal cervical lordotic posture, causing neck and shoulder neuro-musculoskeletal pain.
3. Cranial loading increases the anterior pelvic rotation, causing neuro-musculoskeletal lower back pain.
4. Cranial loading decreases standing heights, leading to intervertebral disc compression.
5. Cranial loading flattens the feet (*pes planus*), which can cause plantar pain and poor balance.

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DECLARATION

The authors declare that this is their own work; all the sources used in this paper have been duly acknowledged and there are no conflicts of interest.

AUTHOR CONTRIBUTIONS

Conception and design of the study: MK, TJE
Data acquisition: MK, TJE, YP
Data analysis: TJE
Interpretation of the data: MK, TJE
Drafting of the paper: MK, TJE, YP
Critical revision of the paper: MK, TJE, YP

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