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Direct measurement of the rhythmic motions of the human head identifies a third rhythm

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ABSTRACT

Introduction: Central to the osteopathic cranial field, and at the same time controversial, is the concept of a unique rhythmic movement believed to originate from a primary respiratory mechanism (PRM). Further, the PRM is reported to manifest as a cranial rhythmic impulse (CRI) on the living human skull. This study explores the rhythmic oscillations of the human head measured directly as physical movements. The aim is to investigate the existence of a third rhythm distinct from the head movements caused by respiratory breathing and arterial pulsing, in an objective and purely experimental study.
Experimental: In 50 healthy individuals, rhythmic oscillations of the head were measured in real-time for 42 min in a supine resting state without any intervention. A newly developed machine for tracking rhythmic movements was used for measurements.
Results: In all individuals, a third rhythm was distinguished as separate from the arterial and respiratory rhythm at all times. The third rhythm was observed as a dynamic physiological phenomenon with a narrow range in resting healthy individuals with a mean of 6.16 cycles/minute (4.25–7.07). The significant contribution to the amplitude of the measured movements was the respiratory breathing and this third rhythm, whereas the contribution from the arterial pulsing were minor.
Conclusion: The present study demonstrates the existence, and normative range of a third physical rhythm detected on the human head. Having developed an objective approach to studying this third rhythm might form the future basis for clinical and physiological studies of craniosacral function and dysfunction.

1. Introduction

A core belief of the whole osteopathic cranial concept is the existence of a rhythmic movement different from the respiratory breathing and the arterial pulse. This new rhythmic movement was named the primary respiratory mechanism (PRM) by Dr. William G. Sutherland, the developer of osteopathy in the cranial field (Sutherland 1939). Since the beginning of osteopathy in the cranial field, the existence and nature of the PRM have created a continually controversial debate in scientific literature and public forums.

A manifestation of the PRM is postulated to be a movement referred to as the cranial rhythmic impulse (CRI) when palpated or measured on the head. Palpation of the CRI is central in the craniosacral evaluation and is used worldwide by a high number of therapists as part of craniosacral assessments concerning Cranio-Sacral Treatments (CST) and in osteopathy in the cranial field. From a scientific point of view, evidence for reliability in craniosacral assessment is not clear. Interobserver agreement is lacking, and palpation studies report on a wide range of CRI's (review in Nielson et al., 2006). A significant source of the criticism and controversy of both the existence and reported range of the CRI in humans is the subjective approach to study the CRI by palpation. An objective approach to study the existence of the CRI was attempted by Dr. Viola Fryman (1971), measuring physical movements on the head directly. The drawback of the direct measurements was a high pressure on the head from the equipment used, and that participants had to hold their breath to exclude respiratory movements. Other studies have used indirect measurements (review in Nielson et al., 2006).

In line with the study of Fryman (1971), we developed a machine to measure rhythmic movements as a direct physical

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movement on the head. The aim of the study was to (1) characterize the rhythmic movements on the head relating to the arterial, respiratory, and a possible third rhythm (2) describe the nature of the third movement, and (3) define the normative range of the third rhythm in humans using an objective method.

2. Materials and methods

2.1. Apparatus

A machine was developed by Meulengracht Measurement® to be able to obtain direct physical movements of the living head in a real-time sampling of data. In short, two servo actuators were positioned on the skin at the positions of the temporal mastoids, keeping a persistent contact of 10 g at all measure times. The servo actuators were CAL 12-010-5 (SMAC Corporation 5807 Van Allen Way Carlsbad, California, USA 760-929-7575), having a sensitivity to detect physical movements of 1 μm. Software was designed by the Danish National Metrology Institute to track any rhythmic movements using Fourier transformations. The Fourier Transformation is a mathematical method used here to identify repeating rhythms in the measurements obtained from the servo actuators. A Fast Fourier Transformation algorithm using 20 measure points per second was used to obtain a real-time measurement of rhythmic movements.

The whole machine construction, metrology, and measurements were independently tested by the Danish National Metrology Institute (report DFM-2011-R04), documenting that the machine could accurately and consistently measure physical rhythmic movements down to 5 μm. For a full description of the machine and the technology report see Appendix A.

The stability and noise level of the measurement was performed with an artificial skull, showing a non-moving constant value for both servo actuators during the measurement (data not shown). The software contained an alarm to record if there were any movements of the head that the servo actuators could not follow, e.g., a sneeze or coughing.

In addition to the measurements by the machine, a mouse trapper sensor was placed on the upper belly anterior to the respiratory diaphragm for an independent recording of breathing cycles. A FitBit pulse wristlet was used to get an independent recording of the arterial pulse.

2.2. Participants

The study is registered in the National Committee on Health Research Ethics of Denmark, study number 74980. All participants (n = 50) were volunteers and signed an informed consent form in agreement with the Helsinki Declaration. The participants consisted of 28 females and 22 males with a mean age of 49 years (range 18–92 years). All participants were selected on a first-come basis. The only criteria were the absence of any known present diseases for the individual. Eight individuals had never heard about or received any cranial treatment, 42 individuals had received some manual treatment (massage, craniosacral, Osteopathic Manipulative Treatment) that included the head.

2.3. Conditions and protocol

Each participant was positioned on a treatment table with a pressure and vibration-absorbing material (ErgoPur, 9550, Mariager Denmark) for approximately 50 min. On the skin at the position of the lateral side of each mastoid processes, servo actuators were positioned with a persistent contact of 10 g in all head positions.

The real-time recording of rhythmic movements was performed in the spectrum from 3 to 90 circles per minute (CPM) for 42 min. The participants were not in contact with a therapist at any time; they were just instructed to lie down and relax for approximately 50 min.

Each set of data for all 50 participants was stored on a hard disk and sent for analysis to (Thomas Rosenkilde Rasmussen), all data sets remained blinded until the finish of the whole analysis. Statistical methods were performed using Microsoft Excel Version 15.35, using the data analysis for calculating mean and variance for each data set. The possible correlation between data sets were analyzed finding Pearson's correlations coefficient r, and the significance (p) of the correlation between data sets were found by ANOVA regression analysis.

3. Results

3.1. Identifying a third rhythmic movement, different from the respiratory movements on the human head

The rhythmic movements in the range from 3 to 90 cpm was directly measured using a custom-designed machine for the purpose (data not shown). Repetitive rhythmic movements were identified in real-time analysis using Fast Fourier Transformation. The arterial pulsations were measured ranged from 44 to 78 (mean 57) cpm. The contribution to movements from arterial pulsations is discussed later, here the focus is on identifying a movement different from the respiratory movements.

Fig. 1A shows a data collection window of rhythmic movements identified between 3 and 35 cpm. The x-axis in Fig. 1A is the frequency of movement about time (note that the scale in Fig. 1A is cycles per 2 min). The frequency is obtained by converting the Fast Fourier Transformation analysis to frequency/2 min. The height of a signal on the Y-axis in Fig. 1A, is the maximum distance in μm between the servo actuator signals, for the periodic movement identified in the Fourier Transformation.

Two groups of rhythmic movements were measured on all individuals (n = 50) in the data collection area (Fig. 1A). A narrow cluster of rhythmic head movements was identified at 4–6 cpm, and a more broad cluster of movements from 9 to 24 cpm, for the person measured. The movement with the higher cpm (9–24 cpm) in Fig. 1A was identified as the respiratory breathing, as the same cpm was identified at the respiratory diaphragm (Fig. 1B). The slower rhythm identified (4–6 cpm, Fig. 1A) is a separated third rhythm measured on the head, different from the respiratory and arterial movements. Fig. 1A is the Fourier Transformed signal used to identify periodic movements, Fig. 1C and D, show the raw data, the wave itself from the periodic movements identified in Fig. 1A. The third movement was identified to have a wave function (Fig. 1D) different than the respiratory wave function (Fig. 1C). The respiratory movement showed expansion and contraction following a sigmoid curve (Fig. 1C), whereas the wave function of the third movement (Fig. 1D) show a wave within a wave movement.

The average cpm for the third rhythm, respiratory breathing, and arterial pulsations were calculated as an average from the 42-min measurement of each person (n = 50) (Fig. 2). As shown in Fig. 2, the three different rhythmic movements were always identified as separate unique rhythmic movements, present on all healthy individuals. No significant correlation was evident between the rate of the third rhythm or the respiratory rate or the arterial pulsation. In Fig. 3, the third rhythm was plotted by increasing cpm, illustrating a very narrow range of the rate of the third rhythm in healthy resting individuals with a mean of 6.16 cpm (4.25–7.07), with few outliers in both ends of the scale.

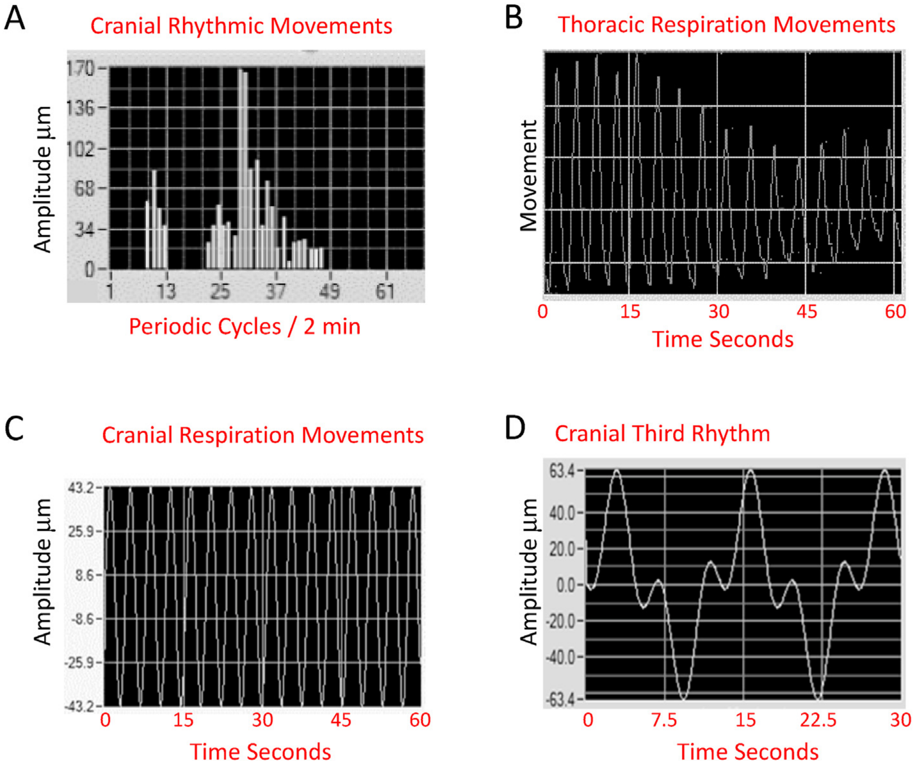

Fig. 1. Measuring of cranial rhythmic movements and separating a third rhythm from the movements of the respiratory breathing**. A**. The x-axis in Fig. 1A is the frequency of movement in relation to time (note that the scale in Fig. 1A is cycles per 2 min). The frequency is obtained by converting the Fast Fourier Transformation analysis to frequency/2 min. The height of a signal on the Y-axis in Fig. 1A, is the maximum distance in µm between the servo actuator signals, for the periodic movement identified in the Fourier Transformation. A window of possible rhythmic movements with frequencies from up 35 cpm is shown (70/2 cycles/min). A narrow cluster of rhythmic head movements was identified at 4–6 cpm, and a broader cluster of movements from 9 to 24 cpm. **B**. A time window of 1 min of respiratory movement measured at the respiratory diaphragm with a respiratory frequency of 16 cpm was observed for the illustrated person. The y-axis is a movement without a specific scale, and the mouse trapper is only to detect the rate of the movement. **C**. The rhythmic movement in the broad cluster (9–24 cpm) identified in **A** is shown. A sigmoid curve with an average cpm of 16 is identified. **D**. The rhythmic movement in the narrow cluster of 4–6 cpm identified in **A** is shown. The movement identified is wave within a wave function with a "shoulder" about halfway between maximum and minimum amplitude. This movement is referred to as the third rhythm.

3.2. The amplitude of rhythmic movements of the head

In Fig. 1A the separation of respiratory and third rhythm is shown. The arterial pulsing with a mean cpm of 57 (44–78) was easily identified as separated from other rhythms. For each periodic movement identified in the Fourier Transformation as respiratory breathing, third rhythm, and arterial rhythm, a maximum distance in µm between the servo actuator signals could be obtained as a measure of the amplitude of head movement. Fig. 1C shown the respiratory breathing rate on the x-axis, and the amplitude on the y-axis. In Fig. 1D third rhythm rate is on the x-axis, and the

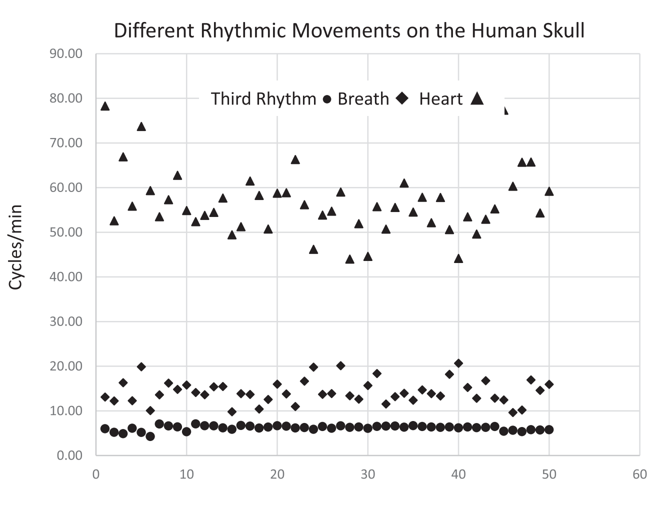

Fig. 2. Average cpm from the third rhythm, respiratory breathing, and arterial pulsing on the head for each person (n = 50). The mean arterial pulsing on the head was 56,65 cpm (44.00–78.28), mean respiratory cpm on the head was 14.34 cpm (9.63–20.65), and the mean for the third rhythm was 6.16 cpm (4.25–7.07).

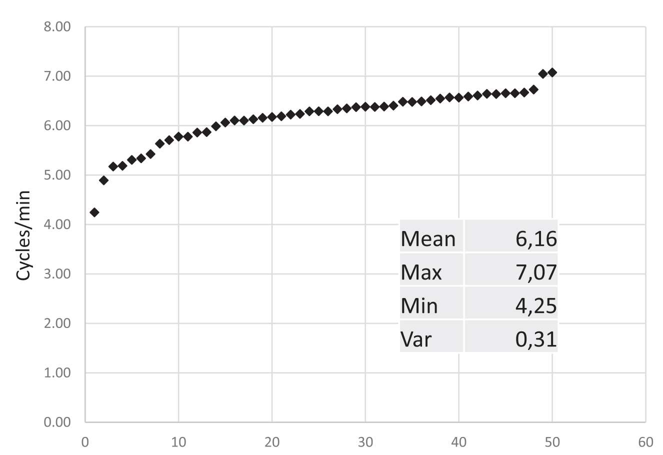

Fig. 3. Mean rate for the third rhythm for each person in the study (n = 50). Each data point is the mean rate for the third rhythm for a person obtained over a measured time of approximately 42 min.

amplitude is on the y-axis. Not shown is the measurement of the arterial rhythm.

Fig. 4 shows the average total head amplitude for each test person on the y-axis. Also shown in Fig. 4, is the contribution to the head amplitude originating from the respiratory breathing, arterial pulsing, and the third rhythm for each individual. The amplitude from the arterial pulsing was always smaller than the respiratory and third rhythm amplitudes. For some individuals, the respiratory amplitude was larger than the third rhythm amplitude and vice versa. On average, for all studied individuals, the mean contributions to head amplitude movement were respiratory 88 μm (321-12), third rhythm 58 μm (194-10), and arterial pulsing 13 μm (53-5).

3.3. The dynamic nature of the third rhythm

Examples of the dynamic ranges of the third rhythm within each individual are shown in Fig. 5. Fig. 5 shows the third rhythm for three individuals, representing a high, middle, and low rate. The dynamic scale of the third rhythm for each individual as maximum and minimum for the 42 min measurements is given in Fig. 5. Further, the real-time measurement allowed to get a measure of the variance of the third rhythm over the 42-min measurement. The graphic representation in Fig. 5 clearly illustrates the dynamic nature of the third rhythm. The level of fluctuation in the third rhythm was individual, and as shown in Fig. 5, the individual with high rate third rhythm (7.07 cpm) had a higher variance in the third rhythm (0.53), compared to the individuals shown with a lower rate third rhythm (5.42 and 4.25, Fig. 5), having a lower variance (0.10 and 0.14 respectively, Fig. 5). There is a significant ($p < 0.001$) and moderate positive correlation ($r = 0.52$) between the third rhythm rate and third rhythm variance for the group of healthy individuals measured ($n = 50$).

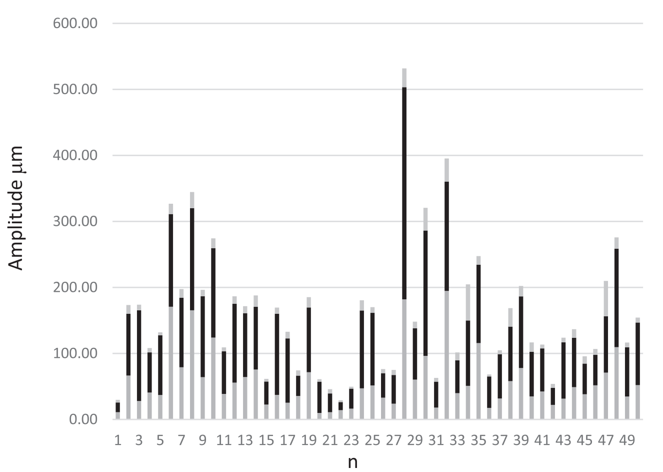

Fig. 4. The amplitude of rhythmic head movements originating from the arterial pulsation, respiratory breathing, and the third rhythm were measured. Grey bar on top = arterial pulse generated amplitude, black = respiratory breathing generated amplitude and grey bar below = the third rhythm generated amplitude.

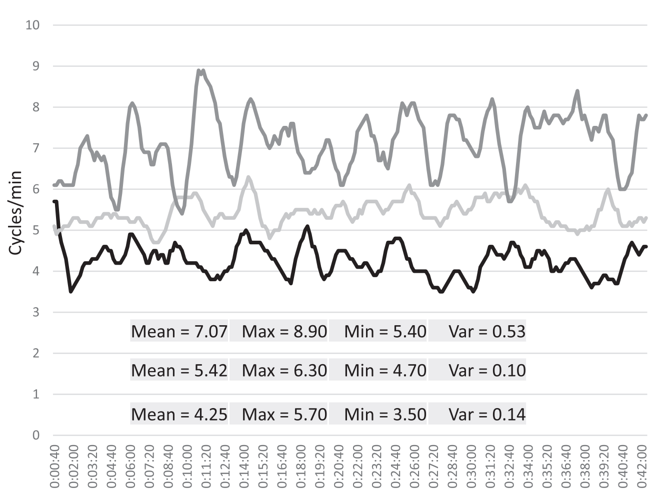

Fig. 5. Dynamic nature of the third rhythm during rest as measured in all participants ($n = 50$). Shown is the third rhythm measured in 3 healthy individuals lying supine over a time of 42 min. The three persons represent the highest, lowest, and mid-range third rhythm. Mean, max, min, and variance are given for each person.

4. Discussion

Dr. William G. Sutherland introduced the primary respiratory mechanism (PRM) as a movement with an inspiration and expiration phase, that was different from the respiratory and arterial movements (Sutherland 1939). Sutherland never described a rate or normative range for the PRM, but after the introduction of the PRM, several studies have accumulated reporting on palpated rates and rates studied by instrumentation of hypothesized head movements (review in Nielson et al., 2006). Studies on palpated rates of possible head movements have shown a wide range from which it has been challenging to create a normative range (review in Nielson et al., 2006).

In this study, a machine was designed that can detect different rhythmical motions on the head. As shown, both the arterial pulsing and respiratory breathing in the body can be detected on the head (Figs. 1, 2 and 4). Also, a third rhythm, different from the respiratory and arterial rhythms, was identified on the human head (Figs. 1–5). The third movement differed in the periodic wave function from the respiratory movement. The respiratory movement showed a sigmoid curve with head expansion and contraction (Fig. 1C), whereas the third movements (Fig. 1D) show a wave within a wave movement. The wave within a wave creates a "shoulder" in the wave movement halfway from maximum expansion to maximum retraction (Fig. 1D). This "shoulder" or observed wave within a wave of the third rhythm, could be the experienced halfway shift (neutral zone), between the flexion and extension phases described by Sutherland. There is a spectrum of low-frequency oscillations, directly or indirectly linked to autonomic nervous system functioning, all in a similar range as the third rhythm reported in this study (McPartland and Mein, 1997).

In history, measuring the ECG, analyzing the different sinusoidal components of the ECG, resulted in a significant shift in the understanding of cardiac physiology. In comparison with the learnings from the ECG, further studies of the more complex wave patterns of the third rhythm identified in this study may give insight into the mechanism behind the generated head movement and its possible relations to the autonomic nervous system. Speculations on the mechanism generating head movements different from the respiratory and arterial, based on the physiology, have been many (reviewed by Ferguson 2003 and Chaitow 1999). Besides, an entrainment model for the CRI has been suggested, also addressing the possible interaction of oscillations between patient and therapist (McPartland and Mein, 1997). However, so far, experimental studies are lacking the exploration of the mechanism behind the head movements. The main question, of the mechanism to a tissue/fluid model, is whether the head movement is a generator of tissue/fluid movements or is a secondary movement of shifting tissue/fluid pressures (Chaitow 1999).

The rate of the third rhythm identified in this study was determined by using a direct measurement of physical head movements, where the interaction between the measured individual and a therapist was ruled out. All healthy humans (n = 50) have this third rhythm on the head, with a mean of 6.16 cpm and a narrow normative range (4.25–7.07). As studies on palpated and measured rates of head movements have shown a wide range (review in Nielson et al., 2006), it is possible that different studies may report on different rhythms under the same name, the CRI. Previous reported experimental studies had found a CRI range from 6 to 14 cpm (; Moskalenko et al. 2001, 2004, 2009, Moskalenko et al., 2001; Upledger and Karni 1979, Lockwood and Degenhardt, 1998) comparable with the first palpation study (Woods and Woods 1961) reporting a CRI range of 10–14 cpm. As the mentioned studies above did not report separation of the CRI and the respiratory rhythmic head movements (; Moskalenko et al. 2001, 2004, 2009, Moskalenko et al., 2001; Upledger and Karni 1979, Lockwood and Degenhardt, 1998), the reported range of the CRI may include or be the head movements generated by respiratory breathing. Indeed, in several individuals measured in this study, the measured movements from the respiratory mechanism were more extensive than the third movement (Fig. 4). Palpating only for the expansion and retraction may often lead to palpation of the respiratory-generated movements. Instrumental measurements of head movements that do not separate the respiratory movements will include a range of movements, including both CRI and respiratory movements, thus creating a broader range of measured cpm. As the visceral pharyngeal basilar fascia is attached on the sphenoid/occiput area, the degree of respiratory-transmitted movements to the head may depend on the tension in this visceral fascial system. The pharyngeal basilar fascia may also explain why, for some individuals, the respiratory-induced movements of the head were more prominent than the third rhythm and vice versa.

The rate of the third rhythm measured in this study is similar to the rate reported in a large palpation study (Sergueef et al., 2011), and with palpations simultaneously measuring the Traube-Hering-Mayer oscillations (Nielson et al. 2001, 2006). Further, the reported rate here is similar to the experimental study by Fryman (1971) using a similar direct measurement of the head movements. Thus, the third rhythm reported here may be the same as the CRI reported in the studies above (Sergueef et al., 2011; Nielson et al. 2001, 2006; Nielson et al., 2001, Fryman 1971).

The experimental demonstration that three different rhythms >3 cpm can be identified on the human living head can be compared to other experimental studies measuring movements on the head, in blood and CSF. Precautions must be made, in comparing an experimental study with experiential studies, as the palpatory experience by any therapist is subjective and individual, this is not to say that one approach or reporting is more or less right, but to be aware that experimental and experiential studies are different and may report on different aspects intended for study.

Performing real-time measurements on each individual over an approximate time of 42 min allowed for a study of the dynamics of the third rhythm within each individual. The observed dynamic range of the average third rhythm was smaller compared to the arterial and respiratory frequencies (Fig. 2). The fluctuation of the third rhythm within each individual was evident for all studied cases (Fig. 5) with a moderate correlation (k = 0.52) between higher third rhythm fluctuations with a higher third rhythm rate. It has been hypothesized that low-frequent (<0.1 Hz) rhythmic movements are influenced by or is influencing the autonomic nervous system balance (Ferguson 2003), and the measured fluctuation in the third rhythm may relate to the balance in the autonomic nervous system. However, further studies are needed to establish the underlying physiology.

The actuators were placed on the skin at the mastoid processes of the temporal bones. Sutures related to the temporal bones are more generally agreed on to stay open later in life compared to other sutures of the skull (Rogers and Witt 1997). However, the experimental setup does not address which parts of the head structures that could be involved in the measured movements, or if the measured movements are movements generated by the bones, this should be a focus for further studies.

The physiological and clinical significance of the third rhythm identified on the living human head remains to be investigated. However, the pulsatile brain is influenced both by arterial and respiratory pulsations (Wagshul et al., 2011), and importantly, a significant respiratory influence on CSF flow has been reported (Vinje et al., 2019) suggesting a possible importance for the head movements on CSF flow. In this study, we show that the respiratory mechanism generates the major head movements together with the third rhythm and that arterial pulsation generates a minor contribution to head amplitude. Vinje et al. (Vinje et al., 2019) reported a significant respiratory influence on CSF flow compared to arterial pulsing. The respiratory influence on CSF flow may be associated with the respiratory movements generating a larger head movement that the arterial pulsing observed in the present study. In the study by Vinje (Vinje et al., 2019), the intracranial pressure (ICP) gradient (dICP), obtained between two intracranial pressure sensors, were measured. The resulting power spectrum (Vinje et al., 2019, Fig. 3a) showed two peaks, the arterial between 0,7 and 1,6 Hz (42–96 beats per minute) and the respiratory between 0,15 and 0,4 Hz (9–24 breaths per minute). Vinje reported that the power spectrum of the dICP, revealed low-frequency patterns below 0,1 Hz, but the contributions to CSF flow was not included in the study. In a study by Nielson (2002), blood velocity measured by laser-Doppler flowmetry also generated a Fourier transformation power spectrum (Nielson 2002) that show the arterial and respiratory movements in blood, similar to the movements in CSF reported by Vinje et al., (2019). In the blood flow, low frequencies (<0,1 Hz) were also identified (Nielson 2002), as was the case in CSF (dICP) (Vinje et al., 2019). Low-frequency movements (<0,1 Hz) as the third rhythm identified on the physical head movement in this study, are present in blood flow velocity (Nielson 2002), as dICP (Vinje et al., 2019) and also reported as oscillations, directly or indirectly linked to autonomic nervous system functioning (McPartland and Mein, 1997). Although the physiological and clinical significance of low frequent oscillation needs further investigation, the influence on blood and CSF circulation reported so far, may point to central importance in human health.

A central aspect proposed by Sutherland was that the PRM unites and coordinates the fundamental physiology of the human body to the level of cellular metabolism. Increasing knowledge of low-frequency movements (<0,1 Hz) in the human body, and their possible importance in blood and CSF flow maintaining human health, is accumulating, and experimental studies that could increase our understanding is most warranted.

5. Conclusion

This study reports on a direct objective measurement of a third rhythmic movement on the human head, giving rational scientific evidence documenting the existence of a rhythmic movement different from arterial and respiratory rhythms.

Sutherland's concept of the PRM is experientially based, and we cannot make a direct comparison between this experimental identified third rhythm and Sutherlands PRM. However, we document a third rhythm different from the respiratory rhythm, and it is possible that this measured rhythm is related to Sutherland experience and is a manifesting part of the PRM concept.

A long-standing debate on using low-frequency movements (<0,1 Hz) in craniosacral assessment by palpation might be clarified, and the future training of therapists using cranial palpation might be improved with reference to both a normative range and nature of the rhythmic movements described in this study. Blood and CSF flow are of central importance in human health, studying the role of low-frequency movements in the human body, may be of great interest in understanding and maintaining human health.

6. Clinical relevance

This study reports the normative range of the rhythmic head movements central to the palpatory diagnostic procedures and therapeutic strategies used in osteopathy in the cranial field.

Head movements identified included a low-frequent third rhythm in human physiology, different from the arterial and respiratory rhythm.

The low-frequent oscillation has been used on a large scale worldwide in cranial osteopathy and craniosacral therapy.

This study forms a new basis for studying the physiological and clinical significance of low-frequency oscillation in humans.

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CRediT authorship contribution statement

Thomas Rosenkilde Rasmussen: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, and, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Karl Christian Meulengracht:** Conceptualization, Methodology, Investigation, Project administration, Funding acquisition, Other: Methodology, Software, Validation assistance was also from third part, The Danish National Metrology Institute DFM-2011-R04, added in Appendix A of the submitted manuscript.

Declaration of competing interest

The authors report no conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article. A full description of the machine and the technology report (Danish National Metrology Institute report DFM-2011-R04) can be found at https://www.bricksite.com/uf/70000_79999/71360/1e02183257d8758b39bb7cf30b2a9d5b.docx.

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