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[原著]

Postural indicators of arousal level while sitting without trunk support

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Summary

Background: Patients with disorders of consciousness show electroencephalogram signs of low arousal and decreased cerebral activity resembling sleep in healthy individuals. Further, activities of wakefulness are not necessarily associated with awareness. Sitting without trunk support may improve arousal and several other physiological parameters in patients with disorders of consciousness patients, which may in turn provide a foundation for improved nursing care and further interventions to relearn activities of independent living.
Aims: This study examined the relationship between arousal and posture in a healthy cohort to identify postural changes indicative of arousal level.
Methods: Thirty healthy volunteers sat on a bench with markers affixed to six points on the upper body for monitoring sagittal posture. Subjects fell asleep and woke spontaneously while sitting, and their posture was analyzed for two-dimensional motion. The state of arousal was confirmed using a simple electroencephalograph of frontal lobe activity.
Results: When arousal declined, sitting posture on the sagittal plane, the head, neck, and upper trunk were anteverted.
Conclusion: The angles of the head, neck and upper trunk on the sagittal plane can be used as an index of low arousal in uncommunicative patients with disorders of consciousness patients to aid in nursing care.

Keywords: sitting posture, disorder of consciousness, arousal, two-dimensional motion analysis, experimental research

Background

The number of patients surviving with prolonged disorders of consciousness (DOC) is increasing progressively, and current estimates of incidence range from 0.5–2/100,000 per year (von Wild et al., 2012). Disorders of consciousness are disorders of arousal and awareness (Laureys et al. 2015). The symptoms of DOC are associated with dysfunctions in the brainstem and thalamus (Posner et al. 2007). The Royal College of Physicians (2003) defines the clinical criteria of DOC as follows:

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(1) there must be no evidence of awareness of self or environment at any time, (2) there are typically cycles of eye closure and eye opening giving the appearance of a sleep–wake cycle, (3) hypothalamic and brainstem functions are usually sufficiently preserved. Also, in DOC, wakefulness and awareness are dissociated, while wakefulness, in which eyes are open and there is some degree of motor activity, is normally associated with conscious awareness.

Furthermore, no effective treatment has been established for DOC (Lancioni et al., 2010). Several treatments have been tested for DOC, including drugs, cerebral or spinal cord stimulation, and sensory stimulation, which in some cases have improved arousal and communication. Elliott and Walker (2005) suggested the need for development of active rehabilitation focusing on maintaining and improving preserved motor function. In addition, Elliott et al. (2005) found that a standing position test using the tilt table improved recovery as measured by the Wessex Head Injury Matrix. Similarly, it was reported that some nurses applied sitting without trunk support as a postural intervention to improve brain activity and movement (Okubo 2011, Hayashi 2011).

In order to maintain the sitting posture against gravity, a complex system of postural control mechanisms for integrating somatosensation with muscle activity is required (Shumway-Cook and Woollacott, 2012). The circuits for this postural control system originate in the brainstem (Takakusaki et al., 2003), as does the center of arousal. It has been speculated that signaling from this arousal system is reduced in DOC and that sitting without trunk support induces neuroplastic changes that facilitate output from the arousal center.

Sitting without trunk support has been examined as a nursing intervention to improve arousal in DOC patients, thereby providing a foundation for additional interventions for independent living. Indeed, Miyata et al. (2015) reported that nurses use this practice for DOC patients with physical disuse to assess activities of daily living, improve respiration, adjust circadian rhythms, and encourage independent sitting. Furthermore, a regimen of sitting without trunk support was reported to improve eye and finger movements as well as vocalization concomitant with EEG α and β wave activation (Okubo, 2011). It has also been reported that the α and β waves of the frontal lobe during tooth brushing were more activated in the position sitting without trunk support than in the supine position (Hayashi, 2011).

Consequently, it is possible that sitting without trunk support may actually promote the recovery of brain activity associated with arousal. We speculate that nursing interventions that improve independent sitting without trunk support may further enhance DOC recovery. However, there is no empirical research on the relationship between arousal and posture while sitting without trunk support to verify such improvements.

In order to establish this care regimen for recovery of independent living, physiological evidence and further demonstrations of efficacy are required. We conducted this study to identify postural indices of arousal that can aid in nursing practice for care of DOC patients.

Aims

The aim of this study is to clarify the relationship between arousal and

Table 1. Characteristics of the study participants

(n = 30)

Item	Classification	n (%)
Age category (y)	18–19	10 (33.3)
	20–24	13 (43.3)
	25–29	1 (3.33)
	30–34	3 (10)
	35–39	0 (0)
	40–45	3 (10)
Sex	Men	15 (50)
	Women	15 (50)
Height (cm)	140–149	1 (3.33)
	150–159	8 (26.7)
	160–170	11 (36.7)
	170–180	9 (30)
	180	1 (3.33)

posture when sitting without trunk support. Such information could provide a basis for the development of better nursing practices for DOC patients.

Method

Design

Trials with sequential controls

Participants

Thirty healthy young adults (15 male, 15 female; age, 23.3 ± 7.1 years; height, 165.5 ± 9.0 cm) volunteered for this study by responding to advertisements (Table 1).

Volunteers were screened to exclude those with histories of brain damage, movement dysfunction, chronic pain, pathologies of the spine or lower extremities, and sleeping disorders. This study was approved by the ethics committee of the Faculty of Health Sciences, Hokkaido University. After explaining the purpose of this research both orally and in writing as well as participants' right to confidentiality and refusal, we obtained informed written consent from each participant. The participant's names were encrypted and saved.

Procedures

This study was performed in a laboratory at Hokkaido University of Science between January and May 2015. To model the condition presented by DOC patients, that is a state in which arousal and EEG activity are low, we studied healthy volunteers in a state of quasi-sleep. Brain waves from the EEG were used as indices of arousal. In healthy subjects, EEG power at the beta (β) band (14–30 Hz) declines and theta (θ) band power (6–8 Hz) increases in a state of low arousal (Okuma, 1999; Åkerstedt et al., 2009). Therefore, in this study, we chose a time point when the β power decreased and the θ power increased for at least twenty seconds compared to the waking EEG as the demarcation between waking and low arousal. As a baseline reference, mean EEG power was measured over one minute during a calculation task requiring the subject to silently count backwards in sevens from one hundred. EEG data were acquired according to the referential derivation method, with the exploring electrode at Fp1 based on the 10–20 electrode system to measure frontal lobe activity and the reference electrode at A1 - A2. The sampling rate was 250 Hz and the time constant was 0.3 s. Throughout the collection of brain activity, the influence of α-clocking was excluded by maintaining closed eyes. Also, subjects were asked to count upwards from one without speaking from the beginning of measurements to exclude brain activity fluctuation unrelated to measurement. Under these conditions, participants were instructed to sleep while sitting when they got sleepy.

The collection and measurement of the posture data conformed to the

Table 2. EEG power at the time of awakening and decreased arousal

(n = 30)

Item		Median (power)	IQR (power)	p	
β power	Average for 1 min during calculation task	712.8	610.4–880.9	<0.001	<0.001
	Average of arousal reduce point 20s	598.3	481.7–731.7	0.186	
	Average of arousal decline time	653.2	531.2–797.5		
θ power	Average for 1 min during calculation task	336.8	275.8–387.3	<0.001	0.192
	Average of arousal reduce point 20 s	437.9	369.8–516.2	<0.001	
	Average of arousal decline time	364.5	294.5–418.5		

Wilcoxon signed rank test

method of two-dimensional motion analysis. Anteroposterior inclination of the trunk is noticeable when DOC patients are sitting without trunk support, so the posture data in this study are based on the relationship between the sagittal plane direction of the head or trunk and the gravitational axis. Specifically, six markers affixed at specific anatomic landmarks were monitored in the sagittal plane by a video camera (Sony HDR-CX 590 V). The markers were attached to vertex (VT), left earhole (EH), seventh cervical vertebra (C7), seventh thoracic vertebra (T7), second sacral vertebra (S2), and anterior superior iliac spine (ASIS) according to previous reports (Kuo et al., 2009; Cacciatore et al., 2011). The video camera was set 180 cm at right angles from the center of a line connecting the sacrum and knee as seen from the left side of the subject with the height equal to the seat. The subject's image was captured from the top of the head to the sole of the foot on the sagittal plane. The markers were commercially available LED lights (BF-AF20P, Panasonic) easily viewed even under low illumination (where arousal tends to decline). Marker movements for tracking changes in posture with arousal state were recorded and analyzed using 2D video motion analysis software (Dipp Motion Pro 2D, DITECT, Japan).

All measurements were made from 13:00 to 15:00 when arousal levels tended to decline. For the purpose of facilitating spontaneous sleep during measurement, subjects were prohibited alcohol on the day before the study, and caffeine and any medications were prohibited for eight hours before measurement. In addition, participants were requested to sleep in the night before for one hour less than usual and to wake-up at least 6 hours before the measurement. Further, subjects took light meals about thirty minutes to two hours before entering the laboratory. In the laboratory, the room temperature was maintained at 23−24 °C, humidity at 50%−60%, and illuminance at 0−2 lux for a comfortable sleeping environment. Daily noises were not suppressed.

Upon entering the laboratory, the participant sat on the bench, and the markers and EEG electrodes were attached. Subsequently, we turned off the lights and asked participants to cross their arms, relax the whole body, and close their eyes. Then the waking reference EEG activity was started to record as described above. During the

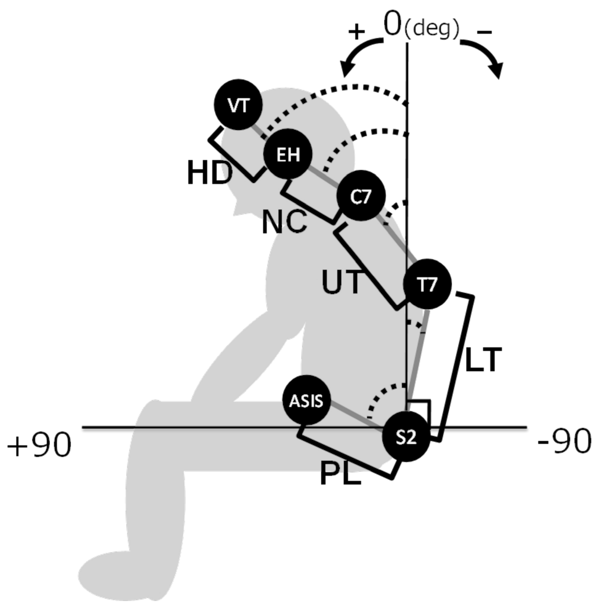

Figure 1. Measurement point of posture and analyzed angle

measurement, researchers observed the EEG in real time on the computer using the software AP Monitor (Miyuki Giken, Japan). The point at which the EEG waveform became slow and low amplitude to the naked eye was regarded as the provisional arousal reduction point. The EEG was then measured for an additional 5 minutes. After 5 minutes, the researcher spoke out to awaken the participant and the measurement was completed. If waking occurred before 5 minutes had elapsed (as evidence by open eyes or speech, etc.) or if there was a danger of falling due to inclination or swinging the trunk, the measurement was terminated.

Data Analysis

EEG data was subjected to fast Fourier transform analysis (5-second epochs and 128 points weighted) to obtain the absolute EEG band power in β and θ using a software (CSA Play Analysis; Norupuro Light Systems, Inc., Japan).

The provisional arousal reduction point was corrected to the true point based on the EEG, and the posture data was classified according to that true reduction point. In other words, recordings during wakefulness were from the start of measurement to the arousal reduction point, while recordings under low arousal were from the arousal reduction point to the end of the measurement.

The posture data were analyzed for X and Y coordinates on images of each marker generated with 30 samples per second. The generation of coordinates was handled by one researcher. The reliability of generation of coordinates was good, with an intra-class correlation coefficient 1,1 = 0.94 and 1,3 = 0.90. The following five parts of the body were defined according to a line connecting two coordinates: the part of head (HD) connecting VT and EH, the part of the neck (NC) connecting EH and C7, the part of the upper trunk (UT) connecting C7 and T7, the part of the lower trunk (LT) connecting T7 and S2, and the part of pelvis (PL) connecting S2 and ASIS. The angles between each of the five parts and the spatial vertical axis were measured using software to represent posture in the sagittal plane. Each angle was set to zero degrees for the spatial vertical axis, so a positive change indicates the forward direction and a negative change indicates the backward direction (Figure 1). To increase the accuracy of data, analysis times before and after the reduction point were equalized on each subject, so that the reported measurement times during wakefulness and low arousal are shorter than the total time.

All data were analyzed using BellCurve for Excel version 2.00 (Social Survey Research Information Co., Ltd. Japan). EEG band power in β and θ were summarized by descriptive statistics according to arousal level (wakefulness vs. arousal reduction point vs. low

Table 3. Measurement and analysis time

(n = 30)

	min	max	mean	SD
Time from measurement start to arousal reduce point (sec)	30	320	137.4	66.1
Time from arousal reduce point to measurement end (sec)	115.9	436.3	282.6	87.2
Analysis time (sec)	60	433.8	250.9	97.6
Total analysis time (sec)	7526.4			

Table 4. The angle of each part and change amount at the time of wakefulness and low arousal

(n = 30)

Part	wakefulness		low arousal		Amount of change (low arousal - wakefulness)		Average ranking of the change *Kruskal–Wallis test*	*p*
	Median (*deg*)	(Q1-Q3)	Median (*deg*)	(Q1-Q3)	Median (*deg*)	(Q1-Q3)		
HD	51.5	(32.7-73.8)	64.1	(45.2-81.3)	8.4	(2.7 -17.1)	114.87	<0.001
NC	73.5	(59.6-79.9)	78.2	(66.9-84.4)	4.6	(1.0 - 8.2)	98.90	
UT	37.5	(30.2-44.5)	39.7	(31.5-46.2)	1.5	(0.1 - 2.6)	72.47	
LT	-0.9	(-3.4- 2.6)	-1.4	(-5.9- 1.5)	-0.2	(-1.9 - 0.5)	44.93	
PL	73.8	(65.5-79.7)	73.8	(65.5-79.8)	0.0	(-1.1 - 0.7)	46.33	

arousal), and compared by the Wilcoxon signed rank test. Angles for the 5 regions were summarized by descriptive statistics according to arousal level (wakefulness vs. low arousal), and compared by the Wilcoxon signed rank test. In addition, Kruskal–Wallis and Steel–Dwass tests were conducted to compare the changes in the angle among the regions because of the decline in arousal. The statistical significance level was set at $p < .05$.

The researchers were nurses with doctoral degrees and were familiar with quantitative research.

Results

Setting of the arousal reduction point and overview of data

The median β band power of the EEG in wakefulness decreased significantly at the arousal reduction point ($p < .001$). The β band power of the EEG during low arousal did not differ significantly from the arousal reduction point ($p = .186$) but remained significantly lower than in wakefulness ($p < 001$), consistent with known EEG changes (Table 2).

The total mean measurement time was 137.4 ± 66.1 s from the start to the arousal reduction point and 282.6 ± 87.2 s from the arousal reduction point to the end of measurement. For analysis, we used the same measurement times before and after the arousal reduction point (250.9 ± 97.6 s), so the mean total time of the analysis across all 30 participants was 7526.4 s (Table 3).

Posture while sitting without trunk support

The angle and amount of change of each part during wakefulness and low arousal are shown in Table 4. The angles of posture were compared with wakefulness and low arousal using the low arousal reduction point as the demarcation. For the HD, NC, and UT, the angles at the time of low arousal were significantly larger (forward direction) than during wakefulness ($p < .001$). The angle for LT during low arousal became larger in the negative direction (backward direction) than at

Table 5. Multiple comparisons between body parts of angular variation

(n = 30)

Part 1	Part 2	Statistics	*p*
HD	NC	2.25	0.16
HD	UT	4.45	<0.001
HD	LT	5.22	<0.001
HD	PL	5.54	<0.001
NC	UT	3.15	0.01
NC	LT	4.70	<0.001
NC	PL	4.78	<0.001
UT	LT	3.05	0.02
UT	PL	3.21	0.01
LT	PL	0.59	0.98

Steel–Dwass test

the time of wakefulness, but the difference did not become significant, and the angle for the PL was almost unchanged at low arousal compared to wakefulness.

The changes in the angle for each part of the body at the time of wakefulness and low arousal were compared. Kruskal–Wallis tests were performed by obtaining the median change at low arousal, assuming that the median during wakefulness at each body part of each subject was zero. It showed a significant difference in HD, NC, UT, LT, and PL ($p < .001$) (Table 4). In addition, the Steel–Dwass multiple test revealed a significant difference in the relationship between the parts except for HD: NC ($p = 0.16$) and LT: PL ($p = 0.97$) (Table 5).

Discussion

In this study, the relationship between the posture and the arousal was examined in order to provide empirical data for monitoring the arousal level of DOC patients sitting without trunk support, a nursing intervention that may improve the arousal and other physiological functions.

Since there has been no research papers showing changes in posture during reduced arousal, it is reasonable to consider from the physiological viewpoint of arousal and posture. Since the trunk angle of the sagittal plane in a sitting position, which is the reference for comparison, was not confirmed, this study used the absolute angle for exploratory examination. When arousal declined, the angle formed by head, neck, and upper trunk relative to the spatial vertical axis increased (anteversion or bending forward). In particular, the change in the angle between the head and neck was significantly more pronounced than other changes among the regions. These postural changes are presumably due to reduced activity of the antigravity muscles supporting each part of the body. Muscle tension declines markedly during non-REM sleep and is completely lost during REM sleep (Bear et al., 2016).

Furthermore, the relaxed posture at the start of measurement further exhibited the flaccid state during low arousal. In particular, suboccipital muscles are activated in order to hold the head up against gravity. The force necessary to keep one’s head horizontal would be approximately 10% of one’s weight, and the center of gravity of the head and the torque are balanced by the atlantooccital joint as a fulcrum. However, as the activity of suboccipital muscles declines with low arousal, the balance of torque collapses and the head drops down from the weight (Neumann, 2013).

On the other hand, in the lower part of the trunk and the pelvic region, the spinal column is joined by interbody and apophyseal joints, and bending is restricted by numerous large and small ligaments such as supraspinous ligaments, interspinous ligaments, and the ligamentum flavum. In particular, the broad and strong glenoid fossa of the apophyseal joint connecting part of the 5th lumbar vertebra to the 1st sacral vertebrae creates robust bony stability (Neumann, 2013). Therefore, the influence of arousal on posture is smaller, even when muscle tension decreases.

The brainstem is critical for regulation of muscle activity to maintain posture (Shumway-Cook et al., 2012). Signals from the cerebral cortex, limbic system, hypothalamus, cerebellum, and basal ganglia input directly or indirectly to the brainstem where they are integrated by various brainstem circuits to produce outputs that adjusts muscle tone (Takakusaki et al., 2004). The brainstem also coordinates arousal and sleep (Kandel et al., 2012). These regions interact to regulate posture and arousal. The results of this study indicate that level of arousal and posture in the sagittal plane while sitting without trunk support are related, at least in healthy adults. As the EEG of DOC patients resembles that of a healthy individual in low arousal or sleep, these results may be translatable to DOC patients and thus provide nurses with an effective indicator of arousal, which is not well indicated by usual signs such as eye opening or closing and motor activity. More vertical head and neck angles are indicative of greater arousal and thus greater capacity for independent living. It is still uncertain if these postural changes are causes or consequences of arousal state. This issue requires further basic and clinical study.

Conclusion

We identified postural changes indicative of the transition from waking to low arousal while sitting without trunk support. It has become clear that the head, neck, and upper trunk moved forward and bent characteristically upon decline in arousal. In brief, the anti-gravity position cannot be retained, especially in the head and neck regions. These postural indicators may prove useful for assessing the arousal level of patients with disorders of consciousness, for whom this particular sitting position appears beneficial.

Limitations

This study examined the relationship between arousal levels and posture in healthy subjects. Clinical studies with DOC patients are needed to confirm these results and determine whether sitting without trunk support can indeed enhance arousal, assist in nursing care, and/or provide lasting improvements for further interventions to facilitate independent living.

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端座位での覚醒低下に伴う矢状面姿勢の変化に関する検討

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要旨

背景：意識障害患者の脳波は脳活動が低下した状態を示し、それは健康な成人の睡眠の状態に類似している．さらに意識障害患者の覚醒状態と意識の内容は必ずしも一致しない．また、意識障害患者が体幹の支持がなく座ることは、覚醒および他のいくつかの生理学的な要素を改善する可能性があるため、自立した生活行動の再学習に関連する新たな看護の介入の基盤を提供し得る．

目的：本研究は、健康な成人における覚醒状態と体幹の支持がない座位の姿勢の関係を検討し、覚醒状態を示す姿勢の変化を明らかにする．

方法：30 人の健康な成人を研究対象者とし、バックレストがないベンチに座りながら眠ったときと目覚めているときの、矢状面姿勢について二次元動作分析を行った．矢状面姿勢のデータは、上半身 6 点にマーカーを貼付し 2 点を結ぶ直線と空間垂直軸となす角度を算出した．覚醒状態は、生体信号収録装置による前頭葉活動を収集し確認した．分析は、記述統計および Wilcoxon 符号順位検定、Kruskal–Wallis and Steel–Dwass 検定を行った．

結果：座位で覚醒が低下すると、矢状面から見た姿勢は前傾し、特徴的に頭頸部が下垂した．

結論：意識障害患者における座位の矢状面姿勢において、頭部と頸部の角度がノンバーバルな覚醒の指標として有用であることが示唆された．

キーワード：座位姿勢，意識障害，覚醒，2 次元動作分析，実験的研究