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Effect of Visual Information Manipulation on Motor Control Indicators in Waiter's Bow Test †

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Abstract

We investigated the effects of manipulating visual information on motor control indicators during the Waiter's Bow Test. The results suggested that visual information occlusion reduced the maximum flexion angles of the lumbar spine and upper lumbar region. Furthermore, subjects who tested negative under the open-eye condition tested positive under the closed-eye condition. Regarding muscle activity in the rectus abdominis and erector spinae muscles, it was suggested that this activity was not affected by visual information. These findings indicate that visual sensory feedback is one factor influencing lumbar motor control. The integration of electromyography and accelerometer systems in this study highlights the role of wearable sensor technologies in quantifying neuromuscular function in Bioengineering. By restricting visual information, a model for sensory reweighting can be established for the design of biofeedback systems, rehabilitation robotics, and assistive devices. The results of this study demonstrate how sensor-based evaluation and sensory manipulation can inform the engineering of diagnostic and therapeutic technologies for motor control assessment.

Keywords: motor control; Waiter's Bow Test; muscle activity

1. Introduction

Motor control is defined as the ability to coordinate the various mechanisms necessary for movement [1]. Research on motor control disorders has progressed primarily in cases of low back pain, with numerous reports documenting the association between trunk motor control disorders and low back pain [2–6]. For example, low back pain patients often exhibit motor disorders in the lumbar region, such as restricted range of motion or movement speed, atypical fluctuations in lumbar motion, and abnormal contraction of trunk muscles [7]. Furthermore, notably slow lumbar spine movement is frequently observed in low back pain patients [8]. Factors influencing these abnormal movement patterns include proposed impairments in the sensorimotor system, such as somatosensory input deficits and musculoskeletal disorders [9].

The movement control system comprises the brain as the control center, the body that outputs movement and receives sensory feedback, and the external environment. Horak [10,11] conceptualizes posture and movement control through six elements: biomechanical constraints, stability limits, postural change-predictive postural control, reactive postural control, sensory function, and gait stability. Particular attention has been given to

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the relationship between movement control and the sensorimotor system, with the influence of proprioception on trunk movement control being emphasized [9]. Furthermore, studies have reported changes in motor control indicators due to alterations in sensory weighting caused by manipulating visual conditions [12].

Recent evaluations of motor control have tested the influence of the sensorimotor system by adjusting visual condition load settings. However, the specific effects on trunk motor control indicators remain unclear. This study aimed to examine the impact of sensorimotor system changes induced by manipulating visual information on motor control indicators during the Waiter's Bow Test.

In addition to the biomechanical perspective, the Waiter's Bow Test is used. Such an approach enables the integration of biomechanics with sensor technologies, computational modeling, and rehabilitation engineering to better understand motor control. For example, wearable sensors and electromyography systems used in this study represent bioengineering tools that enable quantitative assessment of neuromuscular function. Furthermore, visual information is used to provide a model for studying sensory reweighting, which is relevant to the design of biofeedback systems, rehabilitation robotics, and assistive devices. By situating the Waiter's Bow Test within bioengineering, this research contributes to the engineering of diagnostic and therapeutic technologies to improve motor control assessment and intervention.

2. Subjects and Methods

The subjects were 25 healthy young males with no history of musculoskeletal disorders (age 21.8 ± 1.4 years, height 172.8 ± 5.0 cm, weight 65.6 ± 9.2 kg). This study was approved by the Kyoto Tachibana University Ethics Review Board (Approval No. 22-12). All subjects were informed of the study's purpose and provided written consent. The subjects underwent a questionnaire survey, electromyography (EMG) sensor measurements during movement tasks, and accelerometer measurements. The questionnaire collected data on gender, age, weight, and height.

The exercise was performed based on the Waiter's Bow Test, a type of motor control test. The Waiter's Bow Test is a hip-specific forward bending movement performed from a standing position while maintaining the trunk in a neutral position and flexing the hips [13]. In this study, subjects were instructed to stand upright in a natural posture and, upon hearing a signal, bend their bodies from that position and return to the original standing position [14]. After completing at least one practice trial, each subject performed three consecutive trials. This procedure was conducted under two conditions: with eyes open and with eyes closed.

For the Waiter's Bow Test, the examiner observed the movement task, checked for any lumbar movement, and determined whether proper trunk flexion was achieved. Lumbar flexion or extension was considered positive, while the absence of such findings was considered negative.

2.1. Muscle Activity Measurement

Muscle activity measurement was performed as an indicator of motor control during trunk movement tasks. Surface electromyography sensors (Biosignalplux, Creact, Tokyo, Japan) were used for muscle activity measurement. The sampling frequency was 1000 Hz, with a bandpass filter set to 10–400 Hz. Measurement sites were the right rectus abdominis and lumbar erector spinae muscles. Electrode placement followed the positions recommended by Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM). For the erector spinae, two finger-widths lateral to the spinous process at the level of the second lumbar vertebra; for the rectus abdominis, 2 cm lateral to the umbili-

cus. The reference electrode was placed at the right anterior superior iliac spine. Before measurement, the electrode sites were cleaned with alcohol swabs.

To calculate movement angle as an indicator of motor control during trunk movement tasks, measurements were taken using an accelerometer. A 3-axis accelerometer (TSND-151, ATR-Promotions, Kyoto, Japan) was used for measurement. The sampling frequency was set to 100 Hz. Following previous studies, belts were wrapped around the 12th thoracic vertebra (T12), 3rd lumbar vertebra (L3), and 1st sacral vertebra (S1) spinous processes to measure motion angles of the upper and lower lumbar spine. Accelerometers were attached to the belts at these locations [15]. Analysis was performed using angular velocity data obtained from the accelerometers worn by the subjects.

2.2. Statistical Analysis

Data obtained from the EMG sensor and accelerometer were examined for distribution characteristics using histograms and verified for normality via the Shapiro-Wilk normality test. Paired *t*-tests were then performed to verify whether differences existed between variables under open-eye and closed-eye conditions during the Waiter's Bow Test. To investigate the relationship between the open-eye and closed-eye conditions and the assessment results for positive and negative subjects, an adjusted residual analysis was performed using a contingency table. Items with an absolute value of the adjusted residual of 1.96 or higher were considered to have a significant difference. Statistical analysis was performed using R 4.3.0. The significance level was set at 5%.

3. Results

3.1. Significance of Differences in Parameters During Exercise Tasks by Condition

A summary of the results for each parameter in this study is shown in Table 1. Results of paired *t*-tests for each parameter under eyes-closed conditions showed significant differences in maximum lumbar flexion angle and maximum upper lumbar flexion angle. No significant differences were observed for maximum pelvic flexion angle, maximum lower lumbar flexion angle, or lumbar-pelvic rhythm. No significant differences were observed for rectus abdominis muscle activity or erector spinae muscle activity.

Table 1. Values of each variable under open-eye and closed-eye conditions.

Parameter	Open Eyes (N = 24)	Closed Eyes (N = 24)	p-Value
Trunk maximum flexion angle	67.5 ± 10.9	69.1 ± 10.7	0.17
Lumbar maximum flexion angle	33.1 ± 11.5	31.4 ± 15.8	0.03
Pelvis maximum flexion angle	34.4 ± 7.0	33.7 ± 7.1	0.19
Upper lumbar spine maximum flexion angle	11.5 ± 4.8	8.7 ± 18.0	0.04
Lower lumbar spine maximum flexion angle	21.7 ± 8.3	22.8 ± 8.3	0.11
Lumbar-pelvic rhythm (%)	48.1 ± 11.8	50.5 ± 10.7	0.33
Upper lumbar spine/lower lumbar spine movement ratio (%)	58.4 ± 30.3	61.8 ± 36.7	0.32
Rectus abdominis muscle activity	1.3 ± 4.9	1.3 ± 4.9	0.44
Erector spinae muscle activity	15.0 ± 11.1	15.4 ± 11.8	0.74

3.2. Comparison of Variables Based on Group Classification (Positive vs. Negative Groups) and Condition Differences

In the motor control test, participants were classified into two groups: positive and negative. The ratio of participants in each condition was confirmed (Table 2). Under the eyes-closed condition, the positive group consisted of 8 participants and the negative group of 16 participants.

Table 2. Characteristics of variables in the positive and negative groups under open-eye and closed-eye conditions.

Parameter	Open Eyes		Closed Eyes	
	Positive (*N* = 1)	Negative (*N* = 23)	Positive (*N* = 8)	Negative (*N* = 16)
Trunk maximum flexion angle	82.0	66.9 ± 10.7	71.2 ± 12.6	68.0 ± 9.5
Lumbar maximum flexion angle	50.4	32.3 ± 11.1	38.8 ± 11.4	33.7 ± 10.8
Pelvis maximum flexion angle	31.6	34.5 ± 7.2	32.4 ± 6.9	34.3 ± 7.1
Upper lumbar spine maximum flexion angle	19.0	11.1 ± 4.6	16.0 ± 5.3	10.9 ± 4.4
Lower lumbar spine maximum flexion angle	31.4	21.2 ± 8.2	22.8 ± 8.1	22.8 ± 8.3
Lumbar-pelvic rhythm (%)	61.5	47.5 ± 11.7	53.8 ± 9.9	49.0 ± 10.7
Upper lumbar spine/lower lumbar spine movement ratio (%)	60.6	58.4 ± 30.3	76.3 ± 28.3	54.5 ± 38.2
Rectus abdominis muscle activity	1.9	1.3 ± 5.0	0.2 ± 0.3	1.8 ± 6.0
Erector spinae muscle activity	1.8	15.5 ± 10.9	17.1 ± 16.0	14.6 ± 8.9

Mean ± standard deviation.

3.3. Association Between Group Classification and Differences in Conditions

We investigated the association between the presence or absence of visual information (eyes open/closed) and the outcome (positive/negative) (Table 3). The McNemar test revealed a significant difference between visual information and the positive or negative judgment results ($p < 0.01$). The absolute value of the adjusted residual was 1.96 or higher, indicating a significantly higher number of positive cases under the closed-eye condition.

Table 3. Conditions for opening/closing eyes and positive/negative cross-tabulation.

Status of Eyes	Positive	Negative
Open eyes (visual information available)	1 (−2.5)	23 (2.5)
Closed eyes (no visual information)	8 (2.5)	16 (−2.5)

The figures indicate the number of people (adjusted residuals).

4. Discussion

We examined the influence of visual information on motor control during the Waiter's Bow Test. Under the eyes-closed condition, maximum flexion angles at the hip and knee joints were significantly lower compared to the eyes-open condition. This suggests that in an environment where visual information is blocked, the body strategically limits joint range of motion to suppress movement instability by placing greater emphasis on proprioceptive feedback.

The maximum flexion angle of the upper lumbar spine showed a lower mean value and greater standard deviation under the eyes-closed condition, suggesting that the absence of visual feedback increases movement variability and elevates the difficulty of motor control, including that of deep trunk muscles. This increased variability aligns with the limitations of proprioceptive-based motor control noted in previous studies [9].

Visual information plays a crucial role in motor execution. Specifically, during motor planning and execution, visual information serves as vital sensory input when comparing actual sensory feedback with predicted sensory feedback. Focusing on movement angles in this study, the maximum flexion angle was greater for the lower lumbar spine than for the upper lumbar spine, with this trend observed under both open-eye and closed-eye conditions. Furthermore, a significant difference was observed between the open-eye and closed-eye conditions in the maximum flexion angles of the lumbar spine and upper lumbar spine. Previous studies have reported greater mobility in the lower lumbar spine compared to the upper lumbar spine [16,17].

Such results corroborate previous research results and suggest that visual information influences the movement angles of the lumbar spine, particularly the upper lumbar spine, during motor tasks. The results also confirm that the mean maximum flexion angle of the upper lumbar spine was lower and the standard deviation was larger under the eyes-closed condition. In motor control, proprioceptive information modulates strategies to increase or decrease movement variability [9]. In this study, closing the eyes placed greater emphasis on proprioceptive feedback than on visual feedback. This reduced visual sensory feedback during the movement potentially contributed to the decrease in the mean maximum flexion angle and the increase in standard deviation observed in the upper lumbar spine.

Regarding muscle activity, no significant differences were observed in rectus abdominis or erector spinae muscle activity between the open-eye and closed-eye conditions. Previous studies suggest that providing visual feedback significantly reduces muscle activity in primary movers, indicating that the improvement in motor performance from visual feedback may arise through control of muscle activity levels [18,19]. The results of the Waiter's Bow Test in this study show that the muscle activity of the trunk muscles, the rectus abdominis and erector spinae, does not change with manipulation of visual information, yielding results different from previous studies.

The cross-tabulation results revealed significant differences between visual information and positive or negative judgment outcomes. Even in healthy individuals, the loss of visual information suggested that a negative judgment under open-eye conditions could shift to a positive judgment under closed-eye conditions. This implies that relying solely on other sensory information may lead to incorrect adjustments in movement control.

5. Conclusions

The Waiter's Bow Test suggests that blocking visual information and placing greater emphasis on proprioceptive input reduces the maximum flexion angle of the lumbar spine, particularly the upper lumbar region. Trunk muscle activity, such as that of the rectus abdominis and erector spinae muscles, is less influenced by visual feedback-based muscle activity control. These findings indicate that visual sensory feedback is one factor affecting lumbar motor control during the Waiter's Bow Test.

Individuals who received a negative result in the open-eye condition of the Waiter's Bow Test received a positive result in the closed-eye condition. This suggests that even in healthy individuals, when visual information is lost, movement control adjustments may not be performed correctly using only other sensory information. Consequently, restricting visual information and manipulating sensory cue information could potentially be applied to evaluate movement control, focusing on sensory reweighting in the Waiter's Bow Test.

The results of this study provide a foundation for engineering-based diagnostic and therapeutic strategies. First, the observed changes in lumbar flexion angles under visual occlusion highlight the importance of multimodal sensory integration, which supports the design of rehabilitation devices that adapt to altered sensory conditions. Second, the lack of significant differences in trunk muscle activity suggests that bioengineering solutions should focus on kinematic monitoring and proprioceptive feedback rather than solely on muscle activation. Such an approach contributes to the development of wearable systems and smart rehabilitation platforms for motion tracking and sensory substitution. Third, the variability observed in upper lumbar spine motion under closed-eye conditions underscores the need for engineering models that incorporate stochastic elements of motor control, enabling more realistic simulations of human movement. Collectively, the results of this study extend the relevance of the Waiter's Bow Test beyond biomechanics, positioning it as a tool for advancing engineering-based diagnostic and therapeutic strategies in musculoskeletal health.

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However, compared with previous studies, a small sample size including healthy young males limits the generalizability of the results. Therefore, it is necessary to clarify how visual information specifically influences each parameter of the movement metrics, requiring detailed analysis. Additionally, it is necessary to examine other factors, such as muscle strength and flexibility, and other joints, including the hip and thoracic spine, affect performance.

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