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Review Article

Influence of chair seat forward tilt angle on upper limb dexterity improvement in seated tasks: a pilot study

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Abstract. [Purpose] This study aimed to investigate the influence of seat-forward tilt angles on improving upper limb dexterity in seated tasks and to contribute to the development of seating strategies. [Participants and Methods] Seventeen healthy men (age, 20.0 ± 0.5 years; height, 175.1 ± 4.9 cm; and body weight, 63.8 ± 6.7 kg) participated in this study. The forward tilt angles of the seat were set at 0°, 15°, and 30°, with knee pads used in all conditions. The Purdue Pegboard task was used to assess upper limb dexterity, with participants inserting pins into holes in the board for 60 s. Additionally, a visual analog scale was used to evaluate the perceived ease of the task. [Results] The Purdue Pegboard task scores were 30.0 ± 2.5, 30.6 ± 2.7, and 32.5 ± 2.9 for the 0°, 15°, and 30° conditions, respectively. The visual analog scale scores were 75.3 ± 9.8, 76.4 ± 14.6, and 84.1 ± 11.1 for the 0°, 15°, and 30° conditions, respectively. Both measurements showed significantly higher values under the 30° condition than under the other two conditions. [Conclusion] These results suggest that a tilt angle of 30° provides the most significant ease and upper limb dexterity.

Key words: Sitting posture, Chair seat forward tilt angle, Upper limb dexterity

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INTRODUCTION

Individuals in 20 countries, mainly in Europe and Asia, spend an average sitting time of 300 min per day, whereas Japanese individuals dedicate an extended period of 420 min[1)]. This prolonged duration in Japan may be attributed to the fact that many individuals perform tasks while seated in their daily lives. Seated postures can be broadly categorized into upright and relaxed postures. Upright sitting entails tilting the pelvis forward and maintaining the lumbar spine close to its physiological lordotic position. Consequently, it is considered to impose less load on connective tissues such as the spinal ligaments[2, 3)], but requires activation of the trunk muscle group to maintain this posture. Relaxed sitting refers to a posture in which the pelvis is tilted backward, causing the lumbar spine to flex posteriorly. While this posture does not require strong muscle activity, it increases intradiscal pressure and places a greater load on connective tissues located in the spinal dorsal region, potentially leading to lower back pain[2, 4)]. Relaxed sitting is associated with a decrease in respiratory function due to reduced thoracic mobility resulting from spinal flexion[5)]. It also increases the risk of pressure injuries on the buttocks in older adults and individuals with disabilities[6, 7)]. Moreover, Miyadera[8)] and Asahina et al.[9)] reported that the efficiency of tasks performed using the upper limbs on a desk decreased when in a relaxed sitting posture. These findings suggest that a relaxed sitting posture not only affects physical function, but also negatively impacts performance.

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Based on the aforementioned information, adopting an upright sitting posture is more favorable for task performance while seated compared with adopting a relaxed sitting posture. However, maintaining an upright sitting posture for extended periods poses a challenge because of the need to activate the trunk muscle group, leading to muscle fatigue. To address this issue, various devices have been developed to maintain an upright sitting posture with minimal muscle activity. Hirata et al.[10] reported a decrease in trunk muscle activity in an upright sitting posture by using a device attached to a desk to provide frontal support to the trunk. Suzuki et al.[11] and Hirata et al.[12] stated that tilting the seat forward and supporting the lower limbs with the knees could reduce muscle activity in the trunk and neck muscle groups while maintaining an upright sitting posture. Furthermore, Sumi et al.[13] investigated the effects of maintaining an upright sitting posture supported by a forward-leaning seat and knee support from a work efficiency perspective. They reported a significant increase in the number of characters typed during a 10-min typing task while maintaining an upright sitting posture with a forward-leaning seat compared with the condition where the pelvis was not tilted forward on a regular chair. These findings suggest that tilting the seat forward and supporting the knees can facilitate the comfortable maintenance of an upright sitting posture and improve efficiency in tasks performed with the upper limbs.

However, to the best of our knowledge, studies examining the optimal forward tilt angle of a seat to improve upper limb dexterity in seated tasks have not been reported. Therefore, the purpose of this study was to investigate the effects of different forward tilt angles of the seat on the improvement of upper limb dexterity in seated tasks. By elucidating the optimal forward tilt angle of the seat that maximizes upper limb dexterity, this study aimed to contribute to the development of wheelchair seating strategies aimed at improving the efficiency in seated tasks.

PARTICIPANTS AND METHODS

The participants included 17 healthy men (mean age, 20.0 ± 0.5 years; mean height, 175.1 ± 4.9 cm; mean body weight, 63.8 ± 6.7 kg). Participants were excluded if they experienced pain while sitting on a chair; had back pain in a sitting posture; or had a history of surgery, rheumatism, or neurological disorders. This study was approved by the 2022 Ethics Committee of Kawasaki University of Medical Welfare (approval no. 22-005). Written informed consent was obtained from all participants.

As experimental conditions, previous studies such as those by Suzuki et al.[11] and Hirata et al.[12] have used chairs with a seat-forward tilt of 22°, while others, like Sumi et al.[13], have employed chairs with a 30° tilt in their experiments, reporting on muscle activity and work efficiency at these angles. It can be surmised that at seat-forward tilt angles exceeding 30°, the excessive force causing the buttocks to slide forward may make it difficult to maintain posture. Thus, the experimental conditions included seat-forward tilt angles of 0°, 15°, and 30° from the horizontal plane. In studies using a forward-leaning seat, maintaining posture becomes challenging because the buttocks tend to slide forward. Therefore, previous studies utilizing forward-leaning seats have incorporated a “knee pad” to stabilize the seated posture[11–13]. Additionally, Kataoka et al.[14] reported that, even when the seat is not tilted forward, the use of a knee pad improves task ease. In this study, three distinct forward tilt angles were employed as experimental conditions. A knee pad (Hashimoto Prosthetic Manufacturing Co., Ltd., Okayama, Japan) was used to provide frontal support to the knees and stabilize the seating posture. This knee pad is designed with urethane material on the surface in contact with the body to minimize knee pain. It allows for the adjustment of height, position (front to back), and angle, ensuring adequate support for the knees. Additionally, an experimental chair (front seat height: 500 mm, seat depth: 400 mm) and a table (TY506T; Nisshin Medical Instruments Co., Ltd., Aichi, Japan) with an adjustable tabletop height (tilt angle: 0°) were used in conjunction with the knee pad.

Each participant was measured while seated on an experimental chair. The authors aimed to devise strategies for wheelchair seating to improve upper limb dexterity in seated tasks. This study serves as a preliminary investigation of this goal, and thus, we hypothetically targeted individuals using wheelchairs. The feet may not make adequate contact with the floor during desk work without using footplates, as wheelchair footplates are not suitable for weight support. Therefore, in this study, the position of the buttocks on the seat was adjusted in all experimental conditions to ensure that the front part of the feet made contact with the floor. Additionally, to eliminate the influence of differences in the distance between the body and the desk, the greater trochanter was marked as a reference point on the seat, and the position of the buttocks relative to the desk was standardized. The knee pad was adjusted to a position where the knees could adequately bear weight while seated. Adjustments were also made to the height, position, and angle of the knee pad while carefully listening to user feedback to ensure a comfortable position for the participants. To determine the height of the tabletop of the desk where the task was performed, the difference measure (the difference between the height of the tabletop and the height of the seat) for each participant under the 0-degree condition was calculated using formula (1)[15]. Because the height of the seat’s center changed with the forward tilt of the seat, the height of the tabletop for each condition was standardized relative to the height of the greater trochanter position. This standardization was based on the difference measure calculated under the 0-degree forward tilt condition (Fig. 1).

$$\text{High difference (cm)} = \text{Sitting height (cm)} / 3 - 3 \text{ (cm)} \quad (1)$$

To assess the impact on upper limb dexterity, the primary outcome, we conducted an experiment using the Purdue pegboard task (PPT), following the methodology outlined by Hirata et al[10]. The pegboard is equipped with two rows of 30 small

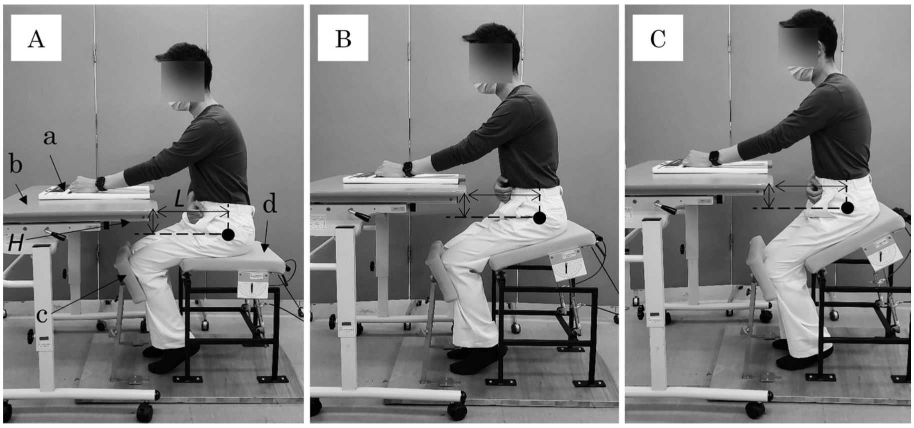

Fig. 1. Experimental condition and measured posture.
A. The 0-degree condition, B. The 15-degree condition, C. The 30-degree condition.
a. Purdue pegboard, b. Table (adjustable height), c. Knee pad (adjustable height, angle, position), d. Experimental chair (adjustable angle of seat).
L, H. The distance between the table edge and the greater trochanter was adjusted equally across the three conditions.

holes each. The task involved inserting one pin into each hole on the board using the non-dominant hand (left hand), and task efficiency was measured by counting the number of pins inserted within a specified time frame. The pegboard was positioned on a desk in front of the participant and aligned with their midline. The rows of holes were adjusted to align with the tips of the middle fingers when the participant extended both upper limbs forward in each seating condition. The participants were instructed to fill in the left column holes first, followed by the right column within the allotted time. They practiced the task twice for 60 s each before the measurements. The task duration was set to 60 s, and the number of pins successfully inserted into the holes was recorded. The starting position involved placing the palm of the non-dominant hand on the pegboard and positioning the other upper limb in front of the abdomen.

As a secondary outcome measure, we used a visual analogue scale (VAS) to assess participants' perceived ease of task execution for each condition. Following the task measurements, participants were instructed to rate the task's ease on a 100 mm VAS. They marked a point on the line, with 0 mm indicating "extremely difficult to perform the task" and 100 mm indicating "extremely easy to perform the task". The marked point on the line was quantified as a numerical value ranging from zero to 100. Additionally, to assess changes in seated posture due to differences in the forward tilt angle of the seat, we utilized a spinal shape analyzer (Spinal Mouse®; Idiag AG, Rapperswil, Switzerland) before initiating the task. The device measured the trunk inclination angle relative to a vertical line. Participants were instructed to maintain their seated posture, as they would during task performance, while sitting on the experimental chair during the measurement.

The measurement order for each condition was randomized to account for the effects of learning and habituation on the task. Measurements for each experimental condition were spaced at least one week apart to minimize the influence of learning or habituation effects. Moreover, to minimize the impact of clothing on the measurements, participants wore only thin fabric clothing on their upper body during the experiments.

Shapiro–Wilk tests were conducted to confirm the normality of each measured variable, and normality was observed for all variables. Therefore, for comparisons among the three conditions, a repeated-measures analysis of variance with Tukey's b post-hoc test was employed. A significance level of 5% ($p<0.05$) was considered significant. All analyses were performed using SPSS (Statistical Package for the Social Sciences) version 23 for Windows (IBM Corp., Chicago, IL, USA). In addition, the effect size and power of the test were determined for the values measured using G*Power 3.1.9.2.

RESULTS

Table 1 presents the following measurements as indicators of upper limb dexterity: the number of pins in the PPT, the values on the VAS reflecting the ease of task performance, and the trunk inclination angle as an indicator of sitting posture before and after the task. The trunk inclination angle is the angle of inclination relative to the vertical axis, with higher values indicating greater forward trunk leaning.

In the PPT, the number of pins were 29.7 ± 2.5, 30.6 ± 2.7, and 32.5 ± 2.9 for the 0-, 15-, and 30-degree conditions, respectively. Significantly higher values were observed in the 30-degree condition compared with those in the other two conditions ($F (2, 32)=10.28$, $p<0.05$, effect size $f=0.389$, power=0.848). As for the secondary outcome measure, the VAS scores were 75.3 ± 9.8, 76.4 ± 14.6, and 84.1 ± 11.1 for the 0-, 15-, and 30-degree conditions, respectively. The 30-degree condition significantly exhibited higher values than the other two conditions ($F (2, 32)=9.88$, $p<0.05$, effect size $f=0.261$,

Table 1. The results of the PPT, VAS, and Trunk inclination angle

	0-degree condition	15-degree condition	30-degree condition	Effect size (d)	Power
PPT (pins)	29.7 ± 2.5**	30.6 ± 2.7**	32.5 ±2.9	0.389	0.848
VAS	75.3 ± 9.8**	76.4 ± 14.6**	84.1 ± 11.1	0.261	0.495
Trunk inclination angle before PPT (degrees)	10.6 ± 3.1**	11.5 ± 3.2**	8.0 ± 2.6	0.464	0.950

Mean ± SD, PPT: puerdue pegboard task; VAS: visual analogue scale.
**p<0.01, repeated measured analysis of variance (ANOVA) with Tukey's post-hoc tests (compared the 30-degree condition and other two conditions).

power=0.495). For the trunk inclination angles, the values were 10.6 ± 3.1, 11.5 ± 3.2, and 8.0 ± 2.6 for the 0-, 15-, and 30-degree conditions, respectively. The 30-degree condition significantly showed higher values than the other two conditions (F (2, 32)=8.22, p<0.05, effect size f=0.464, power=0.950).

DISCUSSION

This study investigated the influence of seat forward tilt angle on upper limb dexterity in seated tasks. The results revealed that in the 30-degree condition, the number of pegs inserted during the PPT, a measure of upper limb dexterity, increase compared with the other two conditions. Additionally, the VAS scores, indicative of the perceived ease of task performance, were higher in the 30-degree condition. Furthermore, the trunk inclination angle was least pronounced in the 30-degree condition. These findings suggest that tilting the seat by 30° enhances upper limb dexterity and the subjective ease of task performance. Based on the results, considerations related to distance and posture during task execution are discussed from various perspectives.

Fitts[16] noted that greater distances to targets and smaller target sizes result in longer movement times in reaching the target. In this study, despite variations in the forward tilt angle of the seat across conditions, the positions of the body, desk, and pegboard were adjusted to maintain uniformity with respect to the position of the greater trochanter as the reference point. Therefore, differences in the position of the pegboard, the target of the task, were disregarded as contributing factors to the observed variations in task efficiency owing to the tilt angle of the seat.

Fray et al.[17] stated that in a relaxed sitting posture with a forward-leaning seat and knee pad, lumbar lordosis decreased compared with the standard relaxed sitting posture on a chair with a more horizontally oriented seat. Additionally, Kim et al.[18] reported a significant reduction in the lumbar flexion angle when using a forward-leaning seat as opposed to horizontal and backward-leaning seats. Kataoka et al.[14] also reported that even with a seat tilt angle of 0°, the use of a knee pad enables easy maintenance of a forward-leaning trunk position. Based on these studies, it can be inferred that in our experiment, where seats with knee pads were used, the seated posture during task performance closely resembled an upright posture. As mentioned earlier, in an upright posture, the pelvis tilts forward, and the lumbar spine approaches a physiologically lordotic position. Nachemson[19] mentioned that the pelvis tilts backward and the lumbar spine bends backward due to hip flexion. Furthermore, Dewberry et al.[20] reported that pelvic tilt contributes to 13.1%–37.5% of total hip flexion, and the greater the hip flexion angle, the more the pelvis tilts backward[21]. These findings suggest that maintaining an upright posture becomes increasingly challenging as hip flexion increases. In this study, despite the greater forward tilt angle of the seat in the 30-degree condition, the forward inclination angle of the trunk was significantly lower. This suggests that the hip flexion angle at the measurement limb position was the shallowest. Additionally, although the forward tilt of the seat causes the pelvis to tilt forward, it is presumed that excessive forward tilt is mitigated by providing support to the knees with a knee pad placed through the thighs. Postural maintenance becomes more challenging as the number of control directions increases. In the 30-degree condition, only control of the forward tilt of the pelvis and trunk owing to the forward tilt of the seat is required. However, in the other two conditions, control of the backward pelvic tilt due to hip flexion is required. Hanada et al.[22] investigated the effect of posture support devices on attention function in individuals with hemiplegia. They found that stabilizing the seated posture using assistive devices resulted in improved visual extinction test scores. Therefore, the use of assistive devices is suggested to automate the attention resources required for posture control. For these reasons, the improvement in upper limb dexterity in the 30-degree condition is attributed to the ease of maintaining an upright posture compared with other conditions, thereby reducing the attention required for posture maintenance.

However, this study had several limitations. First, calculations of the sample size for this study design, using an effect size of 0.6, revealed that the number of participants was insufficient. Second, the chairs used in the experiments differed from standard wheelchair seats. Third, the participants were healthy individuals; thus, additional research is needed to verify whether wheelchair users can maintain their posture in a 30-degree forward-leaning seat. Consequently, a remaining focus for future research is to conduct studies with an appropriate number of wheelchair users and to validate wheelchair use.

In conclusion, the results of this study show that tilting the seat forward by 30° may most effectively improve upper limb dexterity in seated tasks. Facilitating the maintenance of an upright seated posture during task execution can enhance upper limb dexterity. This study demonstrates the effectiveness of tilting the seat forward by 30° as a seating strategy for wheelchair users to improve their upper limb dexterity while seated. However, when tilting the seat forward to enhance upper limb dexterity, it is essential to implement measures to mitigate the risk of the buttocks sliding forward.

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Conflict of interest

The authors declare no conflicts of interest. The authors are responsible for the content and writing of this manuscript.

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