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Original Article

Effectiveness of knee pad as an additional device for wheelchairs in improving upper-limb dexterity during seated tasks: a pilot study

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Abstract. [Purpose] This study aimed to examine how supporting the knee from the front with a knee pad affected upper-limb dexterity while sitting. [Participants and Methods] A total of 14 healthy adult males were included in the study. As a measure of upper-limb dexterity, the number of pins was counted when the Purdue pegboard test was performed for 60 seconds. In addition, the ease of task performance was assessed using the visual analogue scale. There were two experimental conditions, with and without knee pad. The paired t-test was used to detect differences between the two conditions. A p-value of 0.05 was considered statistically significant. [Results] The Purdue pegboard test was 29.4 ± 2.5 and 27.9 ± 3.6 pins with and without knee pad, respectively. The VAS was 76.1 ± 10.3 and 62.9 ± 14.1 with and without knee pad, respectively. Both measured values were significantly higher with knee pad than without. [Conclusion] Supporting the knees from the front with knee pad improves upper-limb functionality while sitting, making it easier to perform seated tasks.
Key words: Knee pad, Wheelchair device, Upper-limb dexterity

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INTRODUCTION

Various sitting postures exist in daily life, including seiza (sitting on the knees), cross-legged sitting, and chair sitting. The lifestyle in Japan has transitioned from a traditional Japanese way of life, where activities are conducted on the floor or tatami, to a more Western lifestyle, where people sit on chairs. Bauman et al.[1)] compared the duration of seated time per day in 20 countries worldwide, primarily focusing on Europe and Asia. Their results demonstrated that the average seated time in the surveyed countries was 300 min per day. In contrast, the average seated time was the longest for Japanese individuals at 420 min. Prolonged sitting time has been linked to increased risk of obesity, cardiovascular diseases, and premature decline in healthy life expectancy[2–4)]. Consequently, reducing seated time during work has emerged as a crucial challenge.

For wheelchair users, reducing seated time can be challenging in terms of employment, education, and other daily activities. The aforementioned increased risk of mortality mentioned is primarily caused by sedentary behavior and lack of movement, leading to issues such as obesity and cardiovascular diseases. Therefore, it is considered desirable to reduce the time spent sitting and increase the active periods by improving the efficiency of tasks performed while sitting, thus completing the work more quickly. To achieve this, it is crucial to create an environment that facilitates upper-limb functionality while sitting. One factor influencing upper-limb dexterity in the sitting posture is the tilt angle of the pelvis. Miyadera[5)] and Asahina et al.[6)]

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reported that an increased posterior pelvic tilt angle, commonly observed in sacral sitting, significantly prolonged the task completion time in the Simple Test for Evaluating Hand Function (STEF). Additionally, Kamegaya[7] investigated the relationship between sitting posture stability and upper-limb dexterity using a regular wheelchair with an unstable seat and a chair with a stable seat. They reported a decrease in upper-limb dexterity in the regular wheelchair sitting posture compared with that in the chair-sitting position, suggesting that sitting posture stability influences upper-limb dexterity.

Therefore, it can be inferred that wheelchair users often experience difficulties in walking due to aging, trauma, or illness, resulting in inappropriate and unstable sitting postures. Numerous devices have been developed and their effectiveness has been evaluated with the aim of correcting improper sitting postures and improving stability in wheelchairs. Fujita et al.[8] reported that increasing the thickness of the rear part of the seat cushion provided posterior pelvic support and could suppress posterior pelvic tilt. Ukita et al.[9] stated that adjusting the shape of the back support could improve asymmetry in individuals with hemiparesis. Nagata[10] examined the effect of anterior knee support on sitting posture stability in severely disabled children. With the posterior pelvic tilt, the buttocks slide forward, and the thighs move anteriorly. The knee support utilized by Nagata inhibits the anterior sliding of the thighs by providing frontal support to the knee region, thereby stabilizing the seated posture. Their findings suggest that the stability of sitting postures can be improved by using additional devices that can be added to wheelchairs.

In seated desk work, tasks require forward inclination of the trunk and pelvis to reach objects. Therefore, devices that can support the trunk and pelvis from the front are desirable as they ensure adequate support. However, studies investigating the impact of devices that enable support from the front on seated stability and work efficiency are relatively limited. Hirata et al.[11] examined the effects of using an assistive device to support the trunk from the perspective of upper-limb dexterity. They reported that supporting the trunk from the front to enhance stability improved upper-limb functionality. However, it is challenging to address decreased mobility in the thoracic region and potential posture instability in the pelvic region below the support point.

The present study aimed to examine whether supporting the knees from the front improves stability of the sitting posture and subsequently enhances upper-limb dexterity during seated tasks. To investigate this, we conducted a pilot study in healthy participants.

PARTICIPANTS AND METHODS

The participants included 14 healthy adult males (mean age, 20.0 ± 0.5 years; height, 175.1 ± 4.9 cm; body weight, 64.7 ± 6.5 kg). Participants were excluded if they experienced pain while sitting on a chair, had back pain in sitting posture, or a prior history of surgery, rheumatism, or neurological disorders. This study was approved by the 2022 Ethics Committee of Kawasaki University of Medical Welfare (No. 22-005). Written informed consent was obtained from all participants.

Two experimental conditions were investigated: with the knee pads, in which condition, the participants performed the task with the aid of knee pads, and; without the knee pads, in which, participants performed the task without knee pads.

To stabilize the sitting posture by supporting the knees from the front, a custom-made device referred to as “knee pad” (manufactured by Hashimoto Artificial Limb Manufacture Co., Ltd., Okayama, Japan) was used in this study. This knee pad was designed with urethane material on the contact surface to minimize knee pain and to allow for height, anteroposterior position, and angle adjustments to provide proper knee support. In addition, an experimental chair (seat height: 500 mm, seat depth: 400 mm, seat angle: 0 °; custom-made by Hashimoto Artificial Limb Manufacture Co., Ltd.) and a height-adjustable table (TY506T; manufactured by Nisshin Medical Industries Co., Ltd., Kitanagoya, Japan) with a fixed tabletop inclination angle of 0 ° were used in the study.

The measurement posture was the seated position in an experimental chair. Although this is a pilot study, these protocols are also intended for future experiments targeting wheelchair users. Foot support of a wheelchair is inappropriate for excessive load support in the forward-leaning working posture. Therefore, performing desk-work without foot support is desirable. However, it can be anticipated that the feet of shorter elderly individuals may not make sufficient contact with the floor. Hence, in this study, the buttock position on the seat was adjusted to allow minimal contact between the forefoot and the floor, thereby preventing excessive load support by the feet. Additionally, to ensure consistency across the experimental conditions, the position of the ischial tuberosity on the seat was marked as a reference point on the seat surface, and the buttock position was standardized for each participant. For the knee pad, detailed adjustments for the height, position, and angle were made while carefully considering the participants’ comfort and ability to bear weight on the knees. The height of the tabletop, which served as an indicator of upper-limb function, was set by calculating the high difference (the difference between the height of the tabletop and height of the seat)[12] for each participant using Equation (1):

High difference (cm)=Sitting height (cm) / 3 – 3 (cm) (1)

Furthermore, the desk position was standardized across the experimental conditions according to the distance from the ischial tuberosity to the rear end of the tabletop (Fig. 1).

To investigate the impact of the experimental conditions on upper-limb dexterity, which was the primary outcome measure, we employed the Purdue Pegboard Test (PPT). The experiment was conducted following the methodology previously

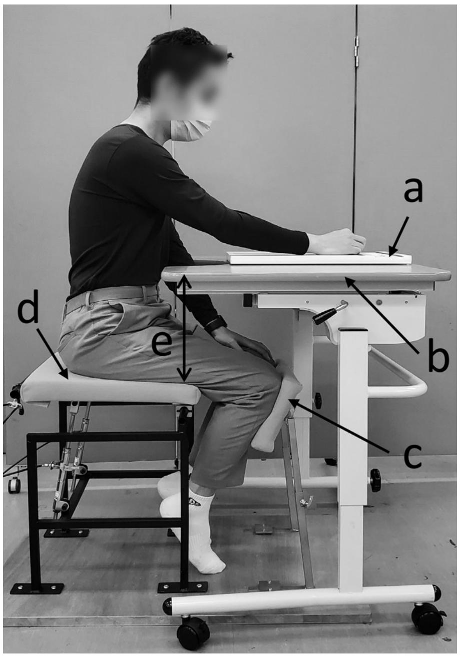

Fig. 1. Measurement environment and measured posture (with-knee-pad condition).
a. Purdue pegboard, b. Height-adjustable table, c. Knee pad, d. Experimental chair, e. High-difference (cm): Sitting height (cm) / 3 − 3 (cm).

described by Hirata et al[11]. The task involved inserting pins into the holes of the board using the non-dominant hand (left hand); the number of pins inserted within a designated time-frame was counted as a measure of task efficiency. The Pegboard was placed on a desk in front of the participants, and the alignment of the rows of holes with pins was adjusted so that they corresponded to the fingertips of the middle fingers with both upper-limbs extended forward. The task involved inserting pins into the left column of holes first, followed by the right column, until the examiner gave the "stop" instruction. Before the measurements, the participants performed two practice sessions lasting 60 s each. The task execution time was also set to 60 s. During this time, the number of successfully inserted pins was recorded. The starting position was defined as placing the palm of the non-dominant hand on the pegboard while resting the contralateral upper-limb on the thigh.

A visual analogue scale (VAS) was used to assess the perceived ease of task performance under each seating condition. Participants were instructed to mark a point on a 10 cm line, where 0 represented "least easy to perform the task" and 100 represented "most easy to perform the task". The marked position on the line was quantified on a scale from 0 to 100.

As a secondary outcome, the changes in sitting posture due to the experimental conditions (with or without the knee pad) were examined using a spinal shape analyzer (Spinal Mouse®, Index Corporation, Tokyo, Japan). Before the task, participants were instructed to assume a comfortable sitting posture on the experimental chair, and the angle of trunk inclination relative to the vertical line was measured. After the task, participants were instructed to maintain their posture without any movement, and the trunk inclination angle was remeasured. To minimize the influence of clothing during measurements, participants were instructed to only wear very thin fabric on the upper body. To account for the potential effects of task learning and adaptation, the order of measurements for each condition was randomized. A time interval of at least one week was also provided between measurements under different experimental conditions.

A preliminary analysis of the data was conducted using the Shapiro–Wilk normality test. To detect differences between the two conditions, a paired t-test was used for normally distributed data-sets. Statistical significance was set at $p<0.05$. All statistical analyses were performed using the IBM SPSS Statistics ver. 23.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Table 1 presents the following measurements as indicators of upper-limb dexterity: the number of pins in the PPT, the values on the visual analogue scale (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 represents the angle of inclination relative to the vertical axis, with higher values indicating greater forward trunk leaning.

For the PPT, the with-knee-pad condition had a higher mean value (mean: 29.4 ± 2.5 pins) than the without-knee-pad condition (mean: 27.9 ± 3.6 pins). The with-knee-pad condition also demonstrated a significant difference, indicating a higher number of pins ($p<0.05$, 95% confidence interval [CI] for the difference: 0.2 to 2.7, effect size (d): 0.469, Power: 0.508).

Table 1. The results of this experiment

	With-knee-pad condition	Without-knee-pad condition	95% CI for difference	Effect size (d)	Power
PPT (pins)*	29.4 ± 2.5	27.9 ± 3.6	0.2 to 2.7	0.469	0.508
VAS***	76.1 ± 10.3	62.9 ± 14.1	7.7 to 18.6	1.045	0.980
Trunk inclination angle before PPT (degrees)**	10.8 ± 3.0	8.2 ± 3.4	0.8 to 4.4	0.808	0.888
Trunk inclination angle after PPT (degrees)	13.4 ± 5.1	11.7 ± 4.7	−1.0 to 4.5	0.350	0.344

Mean ± SD, *p<0.05, **p<0.01, ***p<0.001.
PPT: purdue pegboard test; VAS: visual analogue scale; CI: confidence interval; SD: standard deviation.

Regarding the VAS, the with-knee-pad condition had a mean score of 76.1 ± 10.3, while the without-knee-pad condition had a mean score of 62.9 ± 14.1. The with-knee-pad condition demonstrated a significant advantage in terms of task ease (p<0.01, 95% CI for the difference: 7.7 to 18.6, effect size (d): 1.045, Power: 0.98).

The trunk inclination angle was the secondary outcome measure. The with knee pad condition demonstrated a mean angle of 10.8 ± 3.0 ° before the task, while the without knee pad condition had a mean angle of 8.2 ± 3.4 °. The with knee pad condition sowed a significant forward inclination (p<0.01, 95% CI for the difference: 0.8 to 4.4, effect size (d): 0.808, Power: 0.888). After the task, the with knee pad condition had a mean angle of 13.4 ± 5.1 degrees, while the without knee pad condition had a mean angle of 11.7 ± 4.7 degrees. No significant difference was observed between the two conditions (p=0.192, 95% CI for the difference: −1.0 to 4.5, effect size (d): 0.35, Power: 0.344).

DISCUSSION

In this study, we investigated the effect of knee pad usage on upper-limb dexterity in a sitting posture. The with-knee-pad condition demonstrated significantly higher values for upper-limb dexterity indicators, such as the number of pegs completed in the PPT and the ease of performing the task as indicated by the VAS, compared to the without-knee-pad condition. Additionally, before the start of the task, trunk inclination was significantly greater in the with-knee-pad condition than in the without-knee-pad condition. In the following discussion, we have focused on items with effect sizes of 0.8 or higher.

The increased anterior inclination of the trunk observed before the start of the task with knee pad could be attributed to the improved pelvic stability facilitated by the knee pad. In this study, participants were instructed to assume a comfortable sitting posture on an experimental chair while the trunk inclination angle was measured. In addition, considering wheelchair users, only partial support from the forefoot on the floor was intentionally provided, resulting in insufficient support. Therefore, it can be inferred that a comfortable sitting posture for the participants involved loading the knee pad to stabilize the pelvis. Studies on upright movements have reported that an anterior pelvic tilt leads to forward movement of the knees[13, 14]. Consequently, to support the body weight by loading the knee pad while maintaining the predetermined position of the buttocks and expanding the supporting surface, it was also necessary to tilt the pelvis forward to stabilize the posture.

Furthermore, the anterior inclination of the trunk before task execution could be attributed to the expansion of the forward reach range. Iwamoto et al.[15] reported a strong correlation between the smoothness of the forward-reach trajectory in the sitting posture and the anterior inclination motion of the trunk. Additionally, Chateauroux et al.[16] reported that trunk flexion and shoulder joint rotation have a significant impact on reaching distance. Based on these findings, it can be hypothesized that tilting the trunk and pelvis forward before initiating the task stabilizes the sitting posture, expand the forward reach range, and facilitates the bringing of the upper-limbs and trunk closer to the target object, which, in this case, was the pegboard.

Despite the relatively low effect size of 0.469 and a narrow 95% CI (0.2–2.7), the task performance in the PPT demonstrated a significant improvement under the with knee pad condition. This suggests that the use of knee pad made the task feel easier for the participants. This can be attributed to the enhanced stability of the pelvis through the support provided by the thighs while using the knee pad. Hirano et al.[17] reported that during forward reaching in a sitting posture, weight-bearing on the buttocks of the reaching side significantly decreased. However, the decrease in weight bearing on the opposite side was minimal. This suggests that in order to maintain stability during forward reaching, it is necessary to transfer weight bearing from the buttocks to the lower-limbs and plantar surface on the reaching side, while maintaining weight-bearing on the buttocks on the opposite side. However, in this study, lower-limb support was deliberately limited, making it difficult to shift weight bearing to the lower limbs during the task under the no knee support condition. In contrast, the use of knee pad allowed for a stable pelvic tilt by providing support and enabling task performance primarily through control of the upper body while maintaining a stable posture. The difference between the unstable without knee pad condition and the with knee pad condition, where the pelvic tilt was stabilized by support, resulted in a perceived difference in task ease.

No significant difference was observed in the forward-tilt angle of the trunk after the task completion. As forward inclination of the trunk is essential for smooth task performance in a sitting posture[15, 16], it can be inferred that the participants leaned their trunks forward during task execution, regardless of the presence or absence knee pad.

The results of this study suggest that the use of knee pad during seated tasks increases the forward inclination angle of the trunk, allowing for a more comfortable posture and improved task performance. Additionally, maintaining proper limb position by correcting the posterior pelvic tilt is important for enhancing upper-limb dexterity[5, 6]. Therefore, the use of knee pad can be considered a useful strategy for improving upper-limb dexterity during seated activities.

As the participants in this study were able-bodied individuals, it remains unclear whether these findings can be applied to wheelchair users who are presumed to have weakened trunk muscles. The remaining tasks for the future are to verify the effectiveness of knee pad for elderly parson with weakened trunk muscles and to develop new devices for such elderly person. Furthermore, the experimental chair used in this study had a stable solid seat, which differs from the unstable sling seats commonly used in standard wheelchairs. However, an improvement in upper-limb dexterity was observed with the use of knee pad in individuals with stable sitting postures. This suggests the potential usefulness of knee pad as a strategy for enhancing the upper-limb performance in wheelchair users with unstable sitting postures due to a weakness in lower-limbs' muscle including around the pelvis. However, the installation of knee support on a wheelchair may present disadvantages, such as difficulty in transferring to and from the wheelchair. Addressing these concerns and developing attachment methods that do not impose such limitations on wheelchair users are important areas for future research.

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Conflict of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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