Original Article

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The relationship between the heights of the push switch in the sitting and standing positions

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Abstract

In occupational therapy, we are often involved in designing housing reforms that are comfortable for impaired people. Moreover, occupational therapists should evaluate the disability of each subject to determine a suitable height for the switch operation for the impaired. However, due to some circumstances the switch is not always in the appropriate location. It is necessary to clarify the height of the switch so that it can be easily operated while in various postures. Therefore, we focused on the pushing motion of the wall switch placed at heights of 60cm, 80cm, and 100cm, and aimed to find a suitable height for the switch in the standing and sitting positions by measuring the load on the legs, the muscle activity and the force on the switch. As a result, the lowest weight ratio was found at 100cm in the sitting position during the load shift on the left/right foot before the switch operation. The lowest percentage of maximum voluntary contraction (%MVC) was found at 100cm from the deltoid muscle (Del.), right and left erector spinae (Rt-ES, Lt-ES) in the standing position. Rt-ES and Lt-ES had the same tendency in the sitting position. The smallest force applied on the switch was found at 100cm in the standing position ($p < 0.05$) and the sitting position had the same tendency. There was no significant difference or relevance in the relationship between the time to start the muscle activity and the time to start the switch operation. For both sitting and standing positions, the muscle activity and the shift ratio of the foot load were small when the switch was at the height of 100cm, and the force applied to the switch was also small. Therefore, the appropriate height for the switch is at 100cm in both sitting and standing positions.

Key words

push switch, height of switch, sitting and standing position, load, EMG

Introduction

In occupational therapy, we are often involved in designing housing reforms that are comfortable for the elderly and disabled people, so that the patients suffering physically from aging or cerebral vascular disorder can go back to their homes from the hospitals or other institutions to continue their lives. Occupational therapists should evaluate the disability of each patient to determine various things including the type of handrails and their heights for each physical condition and disorder. They also have to choose the type of switches such as round or square push switch, or the touch sensor switch. However, there is very little scientific evidence that deals with this individual impairment. It is necessary to establish scientific evidence for occupational therapy to determine the switch pushing motion for the individual impairment.

As for the basic background study for these approaches, there are reports related to the improved pinch force after training as a direct

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approach to the upper extremity[1]; to the increased motor units after resistance exercise[2]; to the difference in tactile of the pulp of the finger between those who with previous archery experience and the subjects[3]; to the reach control of the upper extremity[4]. Furthermore, other researches were reported on muscular coordination in relation to the upper extremity and objects[5]; to the dynamic deformation of fingertips[6-9]. In order to prevent disabled and elderly people from falling, Nomura[10] performed a research on the task of pushing the switches located on the wall and at the height of their knees. They evaluated the action of pushing downward in the standing position and explained the necessity of intervention. Tokuda[11] reported an ergonomic survey of push and pull motions by the elderly. It was found that the taps handles set in the public were too high for aged people to use. Further, Voobij[12] measured the push and pull action of 750 elderly people. They reported that a decreased force applied to such actions in both men and women. In the area of rehabilitation, Pennathur[13] surveyed the pushing action and dialing motion of those with their hands or fingers amputated in the U.S. It was found that easy operations depended on the type and the height of the operation. However, in these studies, there are few that mention how to use these results specifically in rehabilitation treatment from the viewpoint of the relationship between biological property and objects. In these studies, groups that exercise daily are reported to have better motion accuracy for index finger pushing force[14,15]. Index finger pushing force is reported to decrease with age[16], the contact area of index finger increased more than that of middle finger[17]. All the reports above explain about the pushing motion to the switch placed on the floor. In our social environment, however, most pushing switches are set on the walls, as seen in elevators or vending machines. The Organization of the Ministry of Land[18] reported that there was no clear switch standard height in both sitting and standing positions. Thus, according to these circumstances, it is necessary to clarify the height of the switch that can be easily operated in various postures.

Therefore, in this study, we focused on the pushing motion of wall switches in the real environment. We set switches at common height of sitting and standing positions, and measured the load on the legs, the muscle activity, and the force on the switches in the standing and sitting positions. These items were clearly timed individually from the start of the push switch to the start of muscle activity, and weight load on foot while pushing the switch. We hypothesized that the height of switch at 100cm would be easy to push in the sitting and standing positions. Moreover, the muscle activity, the load on the legs, and the force on the switches do not change their order in the sitting and standing position. The purpose of this study is to propose suitable switching heights in both sitting and standing positions.

Methods

1. Subjects

The subjects consist of nine male and six female university students aged 22.07 ± 1.16 (mean $\pm$ SD) yrs. Mean height 167.8 ± 8.30cm, Mean weight 59.73 ± 7.96kg. All subjects are right-handed and do not have musculoskeletal nor neurological disorders. For all subjects, we explained the purpose of the experiment and had them sign an informed consent before participation. This study was approved by the ethics committee of Kanazawa University (No.193).

2. Apparatus

A device for the measurement in the sitting and standing positions is shown in Fig. 1. The subjects sat on the chair. Their knees were flexed at 90° angle and their hips were flexed at 90° angle. They sat with their upper limbs lowered.

The task was to push the switch located in the front center with their index finger. The distance between the subject and the switch was the same length of their right upper limb. The heights of the push switch were at 60cm, 80cm, and 100cm. The task in the standing position was to push the switch in the front center at a 45° angle of the shoulder flexion. The heights were the same as in the sitting position.

A load measuring device (KYOWA, Japan:

ECG10101 GSI) was connected to an amplifier to measure the load on the lower extremity. Weight load on foot was recorded for comparison of the right and left loads. Push switch device (TECH JAPAN: VSL06-H5-500N-C) was connected to an amplifier for the measurement of the pushing force. Electromyography (EMG) of the four primary muscles of the upper limb and trunk were recorded using surface electrodes. The EMG signals were recorded from the flexer carpi radialis (FCR), a hand flexor and the anterior deltoid muscle (Del.), a shoulder flexor ; from the right and left erector spinae (Rt-ES and Lt-ES), and a trunk extensor. The FCR signals were measured in pushing motion. After cleaning the subjects skin with alcohol and electrode paste, electrodes (DKH: SX230) were placed on each muscle on the belly in a bipolar configuration of 30mm apart from the center of the electrode. The EMG signals at 1KHz per channel. After data collection we high-pass filtered the EMG signals above 10Hz. EMG activity during isometric and maximum voluntary contraction (MVC) was recorded to allow comparison of across the subjects.

3. Experimental Procedures

The subject sat on a chair in front of the device in Fig. 1. The push switch was put on wooden boards at heights of 60 cm, 80 cm and 100 cm. The subject was instructed to push the switch. Distance from the subject to push switch was the same as the length of the upper limb. The upper limb was lowered at the starting posture. The subject pushed the switch three times at each height. The heights of the push switch in the standing position were set at 60cm, 80cm and 100cm as well as in the sitting.

4. Data processing and analysis

The EMG activity levels of each muscle were calculated into the percentage of EMG activity on MVC. %MVC was compared to root-mean-square (RMS) in 1 sec. All the data were calculated using a computer (DELL: optiplex360) with TRIAS system (DKH, JAAPN). An example of raw data of the subject is shown in Fig. 2. Before the switch was pushed, the foot load was weighed at 5kg. Before pushing the switch, commencement of muscle

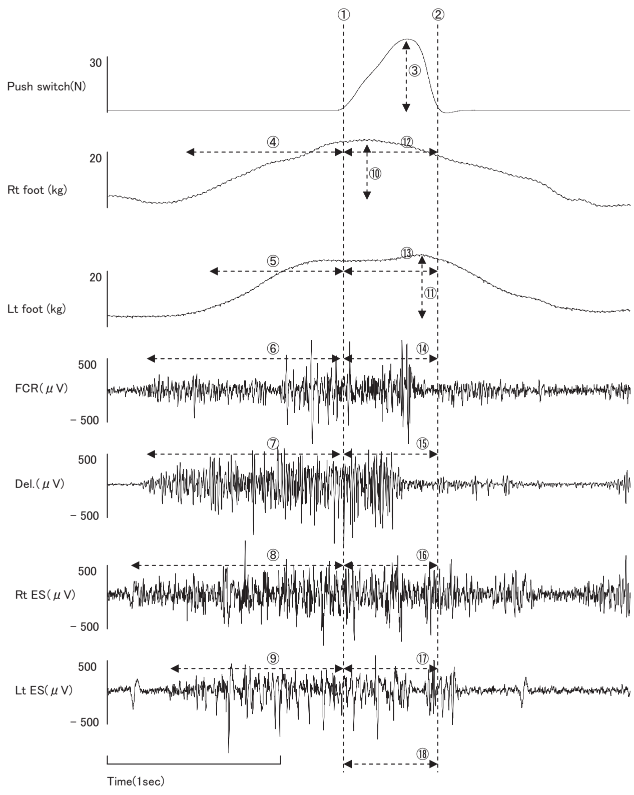

Fig. 2 Example raw data of the subject. The height of the push switch was at 60cm in the sitting position. FCR, flexer carpi radialis; Del., deltoid muscle; Rt-ES and Lt-ES, right and left erector spinae. ①: Starting time of the push switch. ②: Ending time of the push switch. ③: Maximum force of push switch. ④⑤: Time before pushing the switch from the start of the load. (Rt foot, Lt foot) ⑥ ⑦ ⑧ ⑨: Time before pushing the switch from commencement of muscle activity(FCR, Del., Rt ES, Lt ES). ⑩ ⑪: From the minimum to the maximum (Rt foot load, Lt foot load). The maximum load was subtracted by the minimum. ⑫ ⑬: Weight load on the right and left foot while pushing the switch. ⑭ ⑮ ⑯ ⑰: Muscles activity while pushing the switch(FCR, Del., Rt ES, Lt ES). ⑱: Push switch operation time.

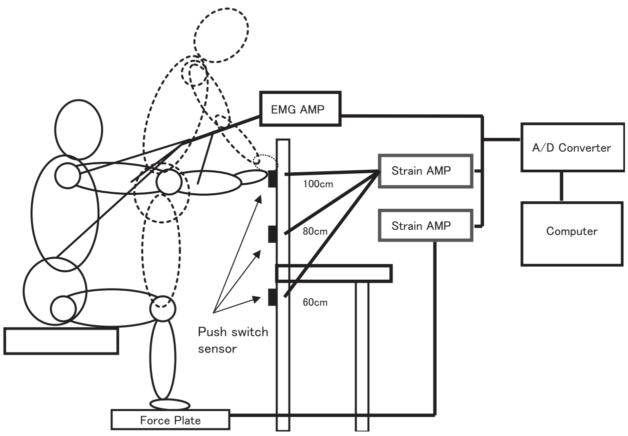

Fig. 1 Postures for this experiment. The height was the same as the sitting position.

Table 1. Comparison of partial weight bearing ratio (Weight ratio). Weight load on the right and left foot while pushing the switch. The calculation of the weight ratio, the difference between the maximum and the minimum of the load was divided by weight. The weight ratio in the sitting position was lower than standing position at all heights. The lowest weight ratio was at 100cm.

Height of the switch position	Items	The ratio of partial weight bearing on right foot in push switch	The ratio of partial weight bearing on left foot in push switch	Weight load on right foot while pushing the switch	Weight load on left foot while pushing the switch
100 (cm)	Sitting	9.96 ± 3.92 *	11.60 ± 3.57 *	43.59 ± 9.00 *	56.41 ± 9.00 *
	Standing	42.19 ± 17.60	19.30 ± 7.35	54.71 ± 6.19	45.29 ± 6.19
80 (cm)	Sitting	11.45 ± 4.07 *	12.05 ± 3.99 *	41.76 ± 8.37 *	58.24 ± 8.37 *
	Standing	53.27 ± 23.01	31.07 ± 14.66	53.11 ± 6.15	46.89 ± 6.15
60 (cm)	Sitting	18.21 ± 8.82 *	19.52 ± 6.01 *	41.99 ± 8.81 *	58.01 ± 8.81 *
	Standing	86.57 ± 25.89	60.46 ± 18.97	55.08 ± 5.56	44.92 ± 5.56

Mean ± SD (%) n=15

*: $p < 0.05$

activity was measured from 200 μV to the actual switching motion. The maximum load was subtracted by the minimum. Starting time of the push switch was measured from 1N. Ending time of the push switch was measured to 1N. %MVC of muscle activity was measured from the starting time to the ending time of the push switch. Maximum pushing force was measured from the starting time of the push switch to the ending time of the push switch. The start time of each parameter was decided according to an increase from the electric potential of the rest. ①: Starting time of the push switch. ②: Ending time of the push switch. ③: Maximum force on push switch. ④⑤: Time before pushing the switch from commencement of load. (Rt foot, Lt foot) ⑥⑦⑧⑨: Time before pushing the switch from commencement of muscle activity (FCR, Del., Rt ES, Lt ES). ⑩⑪: Foot load from the minimum to the maximum (Rt foot load, Lt foot load). The maximum load was subtracted by the minimum. ⑫⑬: Weight load on right and left foot while pushing the switch. ⑭⑮⑯⑰: Muscle activity while pushing the switch (FCR, Del., Rt ES, Lt ES). ⑱: Push switch operation time. Weight ratio: ⑩ and ⑪were divided by weight. Weight load ratio on right and left foot: Each maximum load (⑫, ⑬) was divided by weight.

Statistic Analysis

Statistical analyses of all data were performed using the SPSS12.0J package (SPSS, USA). A two-way ANOVA was used for any difference in height of the push switch while in the standing and sitting positions. Post-hoc test was used for multiple comparisons (Bonferroni). Statistical difference was determined at $P < 0.05$ level for all analyses.

Results

1. Comparison of partial weight bearing ratio (Weight ratio)

There were significant differences of right weight ratio between 60cm and 80cm, and 60cm and 100cm in the sitting position ($p < 0.05$). Weight ratio was the smallest at 100cm in the sitting position. In the standing position, right weight ratio showed significant differences between 60cm and 80cm, and 60cm and 100cm ($p < 0.05$). Weight ratio was the smallest at 100cm in the standing position. There were significant differences of left foot weight ratio as with right foot, and there were significant differences of left weight ratio between 80cm and 100cm in the standing position ($p < 0.05$). The comparison between the sitting and standing positions at all heights had significant differences. All weight ratios in the sitting position were smaller. ($p < 0.05$) (Table. 1).

2. Weight load on right/left foot while pushing the switch

There were no significant differences in the height of the push switch. The comparison between the sitting and standing positions had significant differences in all heights ($p < 0.05$) (Table. 1).

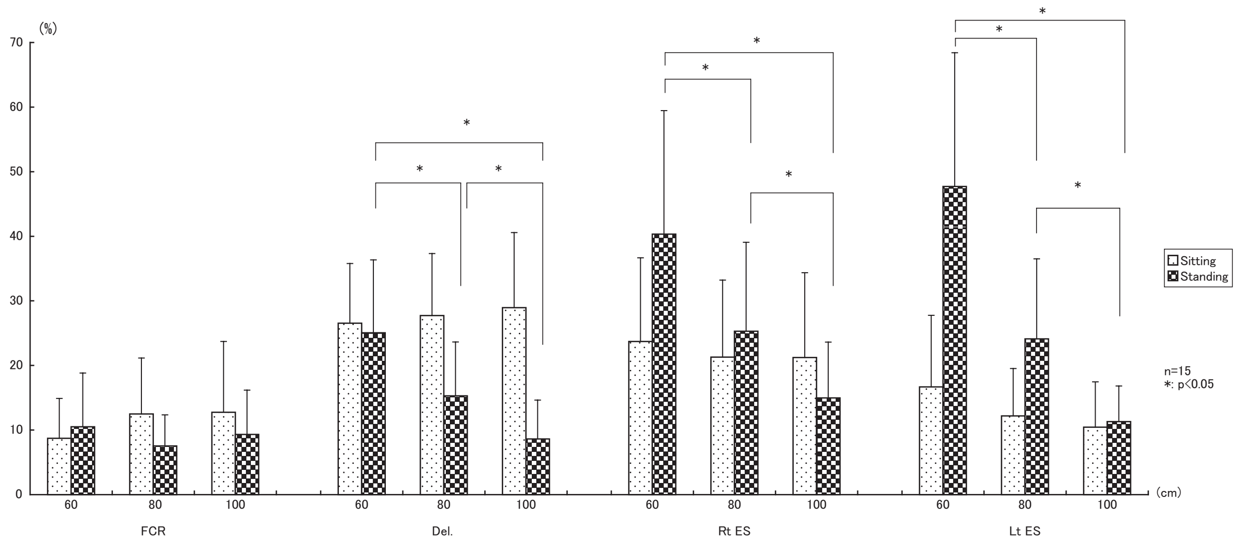

Fig. 3 %MVC of muscle activity while pushing the switch in the sitting and standing positions. Height and muscles.

3. Muscle activity of the pushing motion (from the start of the pushing motion to the end of the motion)

The comparison between the heights of the push switch had no significant differences in the sitting position. There were significant differences in Del, R-ES and L-ES in the standing position ($p < 0.05$) (Fig.3). Rt-ES and Lt-ES had the same tendency in the sitting position.

4. Maximum pushing force

There were no significant differences at all heights in the sitting position. There were significant differences at all heights in the standing position ($p < 0.05$) (Fig.4). The smallest force was at 100cm in the standing position. Sitting position had the same tendency.

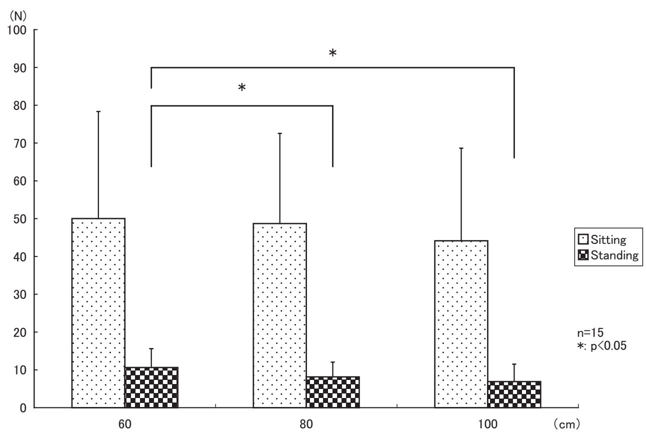

Fig. 4 Maximum pushing force. Comparison of height and posture.

5. The relationship between the starting time of muscle activity and starting of push switch

The comparison between the sitting and standing positions had significant differences ($p < 0.05$) in the heights of the push switch at 60cm, 80cm and 100cm in the deltoid muscle activity. The deltoid muscle in the sitting position started earlier than the standing position at all heights. There were significant differences ($p < 0.05$) in the height of the push switch at 80cm in the right erector spinae muscle activity. The right erector spinae muscle in the sitting position started earlier than the standing position at 80cm. There were significant differences ($p < 0.05$) in the heights of the push switch at 80cm and 100cm in the left erector spinae muscle activity.

The comparison between the heights of the push switch had no significant differences between the heights of the push switch at 60cm, 80cm and 100cm in all muscle activities while sitting. There were no significant differences between the heights of the push switch at 60cm, 80cm and 100cm in all muscle activities while standing (Table. 2). There was no significant difference or interaction for the relationship between the time to start muscle activity and the time to start switch operation.

Table 2. Comparison of height and posture. Standard time was the start of the push switch. Time difference from the start of the push switch to the start of muscle activity. Time difference from the start of the push switch to the start of load. Standard time: Start of the push switch.

Height of the switch position	Items	Time before pushing the switch from outbreak for muscle activity				Time before pushing the switch from outbreak for load		Standard time : Start of the push switch
		FCR	Del	Rt-ES	Lt-ES	Rt foot	Lt foot	
100cm	Sitting	−1.02±0.57	* −1.32±0.33	−1.25±0.44	* −1.69±1.15	−1.10±0.38	−0.97±0.34	0.00
	Standing	−0.85±0.28	−0.98±0.24	−1.25±0.32	−1.21±0.33	−1.01±0.21	−0.72±0.17	0.00
80cm	Sitting	−1.25±0.65	* −1.54±0.55	* −1.51±0.54	* −1.61±0.70	−1.17±0.58	−1.04±0.54	0.00
	Standing	−0.99±0.26	−1.10±0.27	−1.06±0.37	−1.19±0.42	−0.99±0.30	−0.75±0.24	0.00
60cm	Sitting	−1.06±0.20	* −1.26±0.16	−1.16±0.42	−1.00±0.54	* −0.97±0.24	−0.83±0.19	0.00
	Standing	−0.97±0.41	−1.09±0.26	−1.01±0.41	−1.13±0.21	−1.07±0.40	−0.69±0.55	0.00

Mean±SD (sec) n=15

*: $p<0.05$

6. The relationship between the starting times of the load to the starting time of the push switch

There were no significant differences in the heights from the starting time of load to the starting time of the push switch. The comparison between the sitting and standing positions showed significant differences from the starting time of the load on the right to the starting time of the switch at 60cm. ($p<0.05$) (Table. 2).

Discussion

Recently, houses with all electrification have become popular for standard homes and businesses in Japan because of the energy saving requirements and safety. In such environment, it is necessary to use switches to operate various devices. However, the switches are often placed at the height that is not suitable for disabled and elderly people. Moreover, according to the circumstances, it is necessary to research the height of the switch that can be easily operated in various postures. In this study, we conducted experiments in order to propose suitable switch heights in both sitting and standing positions.

As for the right and left foot load shift when operating push switches, we compared the weight ratio between the standing and sitting positions from when the load started to be applied till the end of it. This showed a result that the weight ratio in the sitting position was lower than the standing position at all heights. Also, when we compared the sitting position by height, we found the lowest weight ratio at 100cm. Regarding the weight bearing for each foot, we assume the weight ratio for the foot increased because the flexion angle from the shoulder joint and trunk increased by lowering the switch height. We speculate that there was a large gravitational shift in the basal seat by the increase of weight ratio for the foot, and the switches placed at 60cm, 80cm high would have caused a posture imbalance in the sitting and standing positions. Moreover, because the moved distance of center of gravity was short, the sitting position and the standing positions were stable at 100cm.

When comparing the weight load for the right and left foot during the switch operation, we found a larger ratio on the left foot in the sitting position, and a larger on the right in the standing position. Tsujishita[19] measured the reaction force applied to the lower extremity when reaching the object ahead in the sitting position. They reported that the reaction force increased when reaching out with the upper extremity to the inward rotation. In our study, when pushing the switch with their right hands in the sitting position, we assume that the subjects were supporting the gravity shift on the basal area by increasing the left side weight load because of the high stability on the trunk.

Also, when the switches were at 100cm high, the subjects were able to keep their trunk upright, therefore the load movement was little.

Furthermore, the weight load showed larger value on the right at the three heights in the standing position. Because the basal seat in the standing position is smaller than in the sitting position, it is necessary to flex the shoulder joint and trunk to push switches at the three heights. Therefore, it is likely that the weight load was applied on the right side.

For switching operations, muscle activity is crucial at the upper extremity and the trunk. In order to push the switch, muscle activities such as FCR, deltoid muscle to elevate upper extremity forward, and right and left erector spinae to support trunk when operating the switch with the upper extremity are required. %MVC model of muscle activity of the test muscles enables a comparison by creating standards and eliminates individual musculokeletal difference. When comparing %MVC by height, there were no significant differences of muscle activity at the three heights in the sitting position. There were significant differences of the deltoid and the right and left erector spinae at 60cm and 80cm, 80cm and 100cm, and 60cm and 100cm in the standing position. The muscle activities showed the low vollage at 100cm height in standing. Slijper[20] examined posture control when the subjects touched the objects by finger in the standing position. They reported the result that there were very little electromyographic change in the trunk and lower extremity. It is assumed that the increase of muscle activity of the right and left erector spinae when switching heights to 60cm and 80cm in the standing position was caused by the fact that the increased trunk flexion, the increased reaction force of fingertip and weight load shift at feet caused instability, and that muscle activity increased in order to stabilize the posture. We also assume that the left erector spinae muscle activity ratio was large at 60cm high in order to control the trunk flexion.

When comparing the force applied to switch both in the sitting and standing positions, we found that it was larger in the sitting position at all heights, and it was the least at 100cm in the standing position. When instructed to "push the switch normally" during the experiment, the pushing force in the sitting position was larger than in the standing position. We assume that healthy subjects kept their posture stable because of the wide basal area in the sitting position and brought out a larger force. Maruoka[21] studied the balance of spinal cord injury (SCI) in the sitting position, and explained that they were keeping their balance by rounding back their thoracic spines because they could not make a large motion of bending their trunks. Moreover, Mizukami[22] mentions the importance of avoiding falling down toward the trunk flexion in order not to suffer a SCI in the sitting position. It is likely that the postural instability of people with disabilities is caused by their trunks falling forward during the switch operation because they do not have sufficient muscle support in the trunk and pelvic area when reaching their hands forward in the sitting position, and it eventually causes extra force. Although the weight load shift range between right and left must be small for stability, disabled people feel difficulty in making muscle support of trunk and pelvic, and also support by foot weight load. We assume that the instability in the sitting position has caused them to use extra force. In the training of switch operations for disabled people, it is likely that we need to train them in the switching operations that inhibit the extra force and keep their postural stability in the sitting position.

Comparing the height between the time to start muscle activity and the time to start switching, there was no significant difference or interaction. We assume that the reason why there was no interaction is because the physical phenomenon was similar at 60cm, 80cm, and 100cm in the sitting and standing positions. Furthermore, there was no interaction but similarity between the time to start weight load and the time to start switching, and between the time of maximum weight load and the time of maximum force applied to the switch. With healthy subjects, it is likely that their bodies respond to the environment such as the time to start muscle activation and the time to shift weight load at lower extremity, and adjust themselves flexibly to posture changes with functional and rational actions, even when the height of switch operation was changed. Because the moved distance of the center of gravity was short, the sitting position and the standing position were stable at 100cm.

Conclusion

We focused on the pushing motion of the wall switches in the real environment. The purpose of this study is to propose suitable switching heights in both sitting and standing positions. The height of the switch at 100cm has a small shift range between right and left foot and is suitable for a stable switch operation with minimum force, according to the study of weight ratio in the sitting position.

When the height of the switch is at 100cm in the standing position, muscle activity, foot load weight ratio, and force applied to the switch were small. For both sitting and standing positions, the muscle activity and the shift ratio of foot load weight were small with the switch height at 100cm, and the force applied on the switch was also small. However, there were no influences between the posture and the height of the switch in the switch operation. Therefore, the height of an appropriate switch is at 100cm in both sitting and standing positions.

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押しスイッチの高さと身体肢位との関係

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要　　旨

作業療法では障害者が使いやすい住宅の改修に関わることが多い。そして障害の状態に応じた操作スイッチの高さの設定は作業療法士が対象者個人の状態を評価し設定しなければならない。しかし、スイッチの位置は適切な位置にあるとは限らず、各姿勢で容易に操作できるスイッチの高さを明らかにする必要がある。そこで我々は、壁面にあるスイッチを押す動作に着目し、スイッチの高さを60cm、80cm、100cmに設定し、下肢荷重、筋活動（橈側手根屈筋（FCR）、三角筋（Del.）、左右脊柱起立筋（Rt-ES, Lt-ES））、スイッチにかかる力を測定し、座位と立位における適切なスイッチ高さを示すことを目的とした。その結果、スイッチ操作開始までの左右足の移動で座位と立位で100cmが最も低い体重比であった（$p<0.05$）。筋活動（%MVC）は立位ではDel., Rt-ES, Lt-ESにおいて100cmが最も少なかった（$p<0.05$）。座位でもRt-ESとLt-ESに同じ傾向がみられた。スイッチに係る力は立位では100cmが最も小さな力だった（$p<0.05$）。座位でも同じ傾向がみられた。筋活動開始時間とスイッチ操作開始時間の関係は有意差と交互作用は認められなかった。高さ100cmのスイッチの位置は座位でも立位でも足部荷重の変化が少なく、脊柱への筋の負担も少なかった。そして小さな力でスイッチを押せる高さであった。さらにスイッチ操作開始までの時間に対しては、姿勢とスイッチの高さに影響は認められなかった。これらのことから座位でも立位でも対応できる適切なスイッチの高さは100cmであることが示唆された。