

Effect on cerebral blood flow of using a power assist robot for standing

Abstract

This study investigated the effect on cerebral blood flow of using a power assist robot for standing. Subjects were 10 young adults and 22 elderly adults, and the power assist robot used was a hybrid assistive limb (HAL). The experiment involved two standing conditions: active standing and HAL-assisted standing. Cerebral blood flow, blood pressure, and electrocardiographic measurements were recorded over 3min before and 3min after standing. Cerebral blood flow was significantly lower during HAL-assisted standing in both groups ($p < 0.05$), while blood pressure was significantly lower during HAL-assisted standing in the elderly group ($p < 0.01$). There was little variation in autonomic nervous system activity, as calculated from heart rate variability (fast Fourier transform), in the elderly group. In addition, there tended to be less variation in HF and LF/HF during HAL-assisted standing. These results suggest that using a power assist robot to stand up reduced the capability of feed forward mechanisms to limit orthostatic hypotension, leading to insufficient circulatory regulation.

Keywords: power assist device, sit-to-stand, cerebral blood flow

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Abbreviations: QOL, quality of life; HAL, hybrid assistive limb; APA, anticipatory postural adjustment; HF, high frequency; LF, low frequency

Introduction

Increasing numbers of patients are visiting doctors each year, but hospitals can care for only a limited number of inpatients. Therefore, it is likely that into the future more patients will receive care at home while visiting the hospital on an outpatient basis. As the setting of care shifts from hospital to home, it will be necessary for patients to actively engage in rehabilitation at home so that they can preserve their quality of life (QOL). Retaining the ability to perform movements such as standing up and walking has a particularly large effect on QOL. As elderly adults lose limb strength with age,¹ rehabilitation of standing and walking movements is essential. Machines have been used to perform rehabilitation in recent years and are advantageous in that they reduce personnel costs and are easy to use at home. In the fields of rehabilitation, Hybrid Assistive Limb (HAL) has been attracting attention that applied the disease of bad influence on walking or standing such as stroke or Spinal damage.² HAL is the power assist machine about standing and walking to equip as an exoskeleton and send a biological potential signals to HAL from the electrode through a cable that is affixed to the legs. However, it is necessary to watch out for dizziness, falls, and other such issues associated with reduced cerebral blood flow when performing standing and walking movements. In elderly adults especially, their reduced autonomic function reduces their ability to compensate for decreases in venous return and cardiac output, causing orthostatic hypotension.² The standing using machines are similar to passive standing such as get assistance the standing to people and it suggested that passive standing is more decrease in cerebral blood flow than active standing. Therefore the standing using machines should be paid attention about dizziness or falls. Thus, this study measured the effect on cerebral blood flow of standing up while using a hybrid assistive limb (HAL) that assists in movements such as walking and standing and compared the measurements with those of cerebral blood flow during active

standing in elderly and young people. Cerebral blood flow (ΔO_2Hb), blood pressure, and electrocardiographic measurements were used as indices of the effect on cerebral blood flow.

Materials and methods

Measurement tools and procedure

First, subjects completed a questionnaire to assess personal attributes such as age, height, weight, and sex. Then, for each subject, electrodes for a two-channel infrared oxygen monitor (NIRO-200NX, Hamamatsu Photonics) were applied to the forehead, a blood pressure monitor was wrapped around the upper arm (BP-608 Evolution II, Omron Colin Co., Ltd.), and surface EMG electrodes were applied to the chest (P-EMG plus, Oisaka Electronic Equipment Ltd.). The subject put on HAL before HAL-assisted standing segment. After a subject was fitted with the monitoring devices, he or she sat down in a 30cm-tall chair and maintained the sitting posture for 5min, after which monitoring was started. The subject remained seated for 3min, stood up when given the signal to stand at the 3min mark, and then remained standing for 3min. After those 3min had passed, the subject sat down and rested for 5min. Data were recorded over the 3min before and 3min after subjects stood up. The order of active standing and HAL-assisted standing was randomized for each subject. ECGs recorded from the surface EMG monitor were analyzed using heart rate variability analysis software (Bimutas Video, Kissei Comtec Co., Ltd.) and the indices of autonomic activity LF and LF/HF were calculated. Heart rate variability was analyzed over 120-s intervals starting every 30s, so a total of 9 intervals were analyzed (Figure 1).

Statistical analysis

The data were calculated using Wilcoxon signed-rank test about standing conditions with active and HAL-assisted, Mann-Whitney U test about age groups with elderly and young. Significant difference was setting as p -value < 0.05 and expressed in the figure $p < 0.05^*$, $p < 0.01^{**}$.

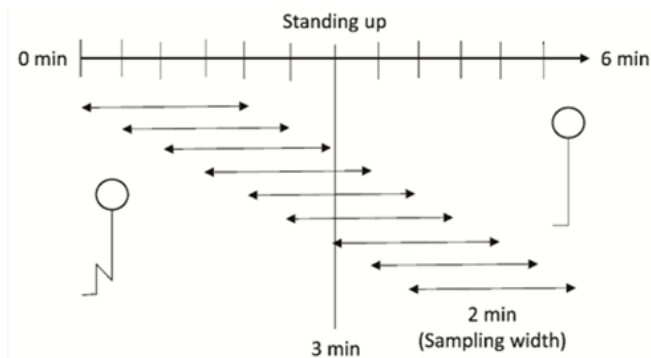


Figure 1 Intervals analyzed for heart rate variability.

Ethical considerations

The study protocol was approved by the Medical Ethics Committee of the University of Tsukuba on October 3, 2012 (Certification No. 682) and conformed to the declaration of Helsinki. Participation was voluntary and all participants provided written informed consent.

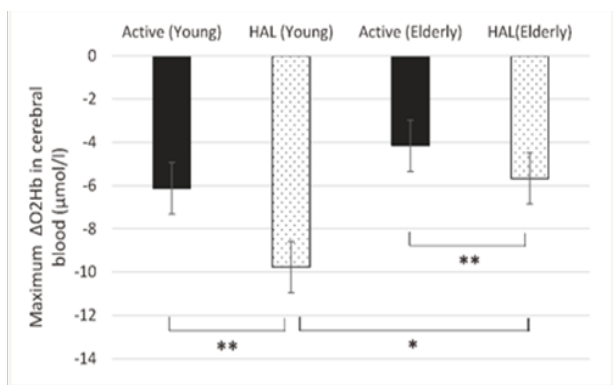
Results

Subject attributes

The subjects were 10 young men and women (22.6±2.2years) and 22 elderly men and women (70.0±3.7years). Average height was 164.1±6.5cm in the young group and 162.1±7.9cm in the elderly group. Seven of the young adults and 12 of the elderly adults exercised regularly. Average sleep time was 5.8±2.5h in the young group and 6.8±1.0h in the elderly group.

Changes in cerebral blood flow

A comparison of the maximum decrease in cerebral blood flow (ΔO_2Hb) is shown in Figure 2. Values differed significantly between active standing and HAL-assisted standing in both the elderly group ($p < .01$) and the young group ($p < .01$). When the age groups were compared, it was found that the maximum ΔO_2Hb was greater in the young group. Besides the values differed significantly between elderly group and young group in HAL-assisted standing ($p < .05$). **Figure 2**



Maximum ΔO_2Hb in cerebral blood.

Changes in blood pressure

Figure 3 shows comparison of the average decreases in blood pressure. As with cerebral blood flow, there was a significant difference between active standing and HAL-assisted standing in the elderly group ($p < .001$). In the young group, however, there was no significant difference. Moreover, there were no significant differences between elderly group and young group.

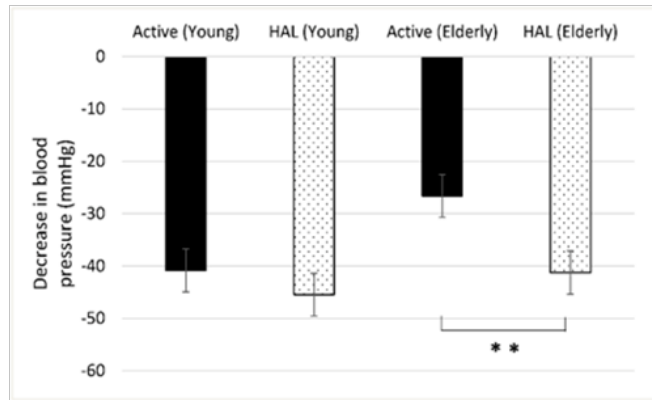


Figure 3 Decrease in blood pressure.

Changes in the autonomic nervous response

Figure 4 shows time-series changes for HF over all intervals. Figure 5 shows time-series changes for LF/HF over all intervals. The HF component decreased from before standing to after standing, so the LF/HF ratio increased from before standing to after standing. Both HF and LF fluctuated more widely in the young group than in the elderly group. When these values were compared between the two standing conditions, a significant difference in LF/HF between active standing and HAL-assisted standing was found at the second interval for the elderly group ($p < .05$). In the young group, however, there was no significant difference in HF or LF/HF at any interval.

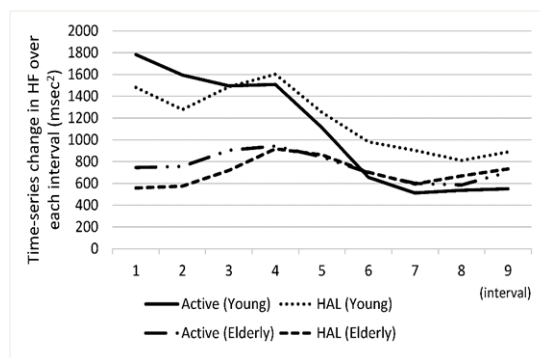


Figure 4 Time-series changes in HF over each interval.

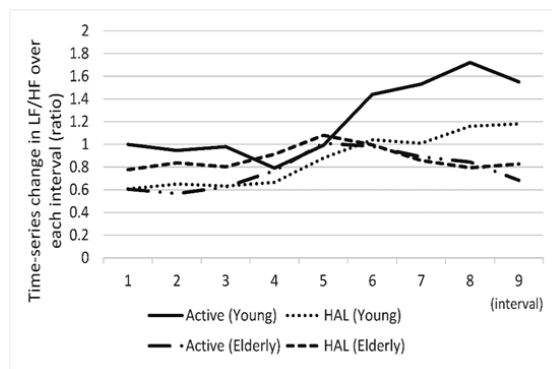


Figure 5 Time-series changes in LF/HF over each interval.

Discussion

The decrease in cerebral blood flow was greater in the young group than in the elderly group. This smaller decrease in the elderly group could be explained by brain atrophy,⁴ which could have narrowed

the measurement range of the infrared oxygen monitor, and by age-related arteriosclerosis, which could have reduced cerebral blood flow directly.⁵ The average decrease in blood pressure was greater in the elderly group than in the young group, indicating the importance of watching out for issues such as dizziness on standing and orthostatic syncope. When cerebral blood flow and muscle activity were compared between the standing conditions, the decrease in cerebral blood flow was found to be greater for HAL-assisted standing. When under voluntary control, HAL detects bioelectric signals emitted from the surface of the skin as a person moves and can reduce the load of movement by providing power assistance before the user moves his or her muscles.⁶ Therefore, when the HAL exoskeleton suit was worn on the legs, the subject performed standing movements at high torque using the power assistance. Standing at high torque is believed to engage the vastus medialis more so than the rectus femoris.⁷ In other words, when subjects stood up using HAL, the most actively engaged muscle was likely not the rectus femoris, the muscle directly involved in standing, but rather the vastus medialis, the muscle that stabilizes the joints. From an anatomical standpoint, the vastus medialis should be less capable than the rectus femoris of preventing downward displacement of blood during standing, which is likely why such marked downward displacement of blood was seen during HAL-assisted standing.

Autonomic activity was probably another major factor that contributed to the decrease in cerebral blood flow during HAL-assisted standing. Although there was no significant difference in autonomic responsiveness, there was less variation in HF and LF/HF activity before and after HAL-assisted standing. A possible reason for this is that the subjects' lack of familiarity with power assist standing and their wearing of the exoskeleton suit while standing up may have impeded the central command by which the central nervous system directly regulates circulation,⁸ or impeded the compensatory postural regulation mechanism called anticipatory postural adjustment (APA), which predicts body sway caused by voluntary movement and attempts to suppress it.⁹ Such types of anticipatory regulation are also called feed forward mechanisms. The fact that APA¹⁰ and reflex responses to movement¹¹ change following injury to the basal ganglia or cerebellum suggests that the central nervous system has various anticipatory feed forward mechanisms for regulating movements. There are also feedback mechanisms that stimulate sympathetic activity when bar receptors react to the decrease in blood pressure that occurs on standing. These two mechanisms help maintain vascular resistance, which prevents problems with vasodilation such as decreased arterial blood pressure and excessive downward displacement of blood.¹² However, even though feedback mechanisms are constantly active, it has been suggested that engagement of feed forward mechanisms can change with experience.¹³ In essence, the large decrease in cerebral blood flow observed in this study appears attributable to a delay in circulatory regulation caused by impediment of central command outputs by factors such as the subjects' concentration being focused on operating HAL, subjects' lack of familiarity with power assist standing, and impairment of posture regulation due to the exoskeleton suit. It was also found that there is less variation in autonomic activity in elderly adults compared with young people. This appears to be associated with the decrease in autonomic responsiveness seen with aging.^{14–16}

Conclusion

In this study, the effect on the cardiovascular system of using a power assist robot for standing was determined and the relationship between humans and machines was explored by comparing results for

active standing and assisted standing. The analysis of cerebral blood flow, blood pressure, and autonomic activity that were measured during active standing and HAL-assisted standing in 10 healthy young adults and 22 healthy elderly adults led to the following conclusions. The decrease in cerebral blood flow (ΔO_2Hb) was significantly larger when subjects stood up using the power assist robot than when they stood up unassisted ($p < .05$). This suggests that the standing conditions influenced the extent of downward displacement of blood due to vascular compression and that a decrease in blood flow was induced by a difference in regulation by the central nervous system. Also, because the characteristics of elderly adults such as reduced autonomic responsiveness and reduced strength impede engagement of feedback mechanisms, particularly when standing up using a standing assist robot, it is necessary to make users aware that they are standing up by a method such as voice alerts.

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Conflict of interest

Author declares that there is no conflict of interest.

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