

Low Visual Acuity is Associated with the Decrease in Postural Sway

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Vision contributes to upright postural control by providing afferent feedback to the cerebellum. Vision is generally classified into central and peripheral vision, but little is known about the respective role of central and peripheral vision for postural control with different visual acuity levels. This study examined the influence of visual acuity and visual field conditions on upright posture. Eleven males (21.1 ± 2.0 yrs) and 15 females (22.2 ± 2.2 yrs) were classified into high (above 1.0 binocular vision) and low (below 0.3) visual acuity groups. Postural sway was measured for 1 min in each of three visual field conditions (central vision, full vision, and no vision). Participants were given only central visual information (central vision), central and peripheral visual information (full vision), or no visual information (no vision). The effect of central vision on postural sway was detected as a difference between no vision and central vision conditions, and the effect of peripheral vision was assessed as a difference between central vision and full vision conditions. The low visual acuity group decreased their sway amplitude in antero-posterior direction using central plus peripheral visual information, but the high visual-acuity group did not. The high frequency sway was significantly smaller in the low visual-acuity group than that in the high visual-acuity group under the no vision and central vision conditions. These findings suggest the necessity of considering participants' visual acuity in examining the role of the visual information from the central and peripheral visual fields. ——— postural control; visual acuity; upright stance; center of pressure; healthy young adults.

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Visual perception is closely related to postural control and provides afferent feedback regarding postural sway to the cerebellum (Loughlin et al. 1996; Loughlin and Redfern, 2001). Visual function is mainly evaluated via visual acuity and the visual fields (Margolis et al. 2002). The former refers to the sharpness of vision, as tested with a Snellen eye chart. The latter refers to the space or range in which objects are visible to immobile eyes. The visual field is divided broadly

into central vision (viewable angle < 2.5 degree) and peripheral vision (viewable angle > 2.5 degree) based on anatomical and functional differences of the retina (Margolis et al. 2002). Hence, their roles in postural control may also differ (Brandt et al. 1973; Hilton et al. 2003; Ishihara et al. 2005). Specifically, the role of central vision in stabilizing posture remains unclear (Okuzumi et al. 1996; Souma et al. 2000; Ishihara et al. 2005).

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Bardy et al. (1999) classified the results of previous studies on the role of central and peripheral vision into the following three theories: peripheral dominance, retinal invariance, and functional sensitivity. According to Berencsi et al. (2005), the first theory emphasizes the superiority of peripheral vision in the control of posture and self-motion (Amblard and Carblanc, 1980). The second theory holds that central and peripheral vision have the same functional role (Bardy et al. 1999), while the third suggests that central and peripheral vision have functionally different but complementary roles in postural control (Nougier et al. 1998). These contradictory concepts may be attributed to different definitions of both types of vision among the studies and to different methods of presenting visual stimuli (Berencsi et al. 2005). In particular, the central visual field is anatomically defined as the central 2.5 degrees of the visual field (Margolis et al. 2002); however, this definition varies in each study by 10 (Nougier et al. 1998) to 60 degrees (Brandt et al. 1973). As mentioned above, there is room for improvement with regard to the definition and the methodology.

Humans control the sway of their center of mass in response to external forces added to their body, floor surface conditions and changes in the surrounding environment. For example, Lestienne and Gurfinkel (1988) reported that people who experienced a spaceflight showed an adaptation of postural control to the microgravity environment such that less somatic sensation was constantly evoked for postural control. Given this report, it is possible that people with low visual acuity have postural control characteristics different from those of people with healthy vision. Furthermore, body sway characteristics in various visual environments may differ between people with low and high visual acuity. Wade and Jones (1997) identified a link between spatial orientation and postural control, because people with low visual acuity cannot precisely perceive the shapes of objects in comparison to people with high visual acuity. As such, individuals with low visual acuity may display inferior self-orientation, which may influence their postural control. According to Sukemiya et

al. (2006), the phenomenon of self-location relative to the external environment as recognized by the visual system is explained through self-centered coordinates that are based on criteria located somewhere within the head. There are many studies that have examined the position of the original point of the visuospatial coordinates (visual egocenter), and it is known that the egocenter is a point at the intersection of median plane of the head with the axis of both eyes. Differences in visual acuity have an influence on these various factors contributing to postural control, and, as a result, a difference may be found in upright postural control between individuals with differences in visual acuity. Hence, it may be important to examine the influence of central and peripheral vision on postural control while also considering the visual acuity of the participants. However, there have not been many previous studies examining the combined factor of visual acuity and visual field on upright postural control.

It has been reported that changes in the function of the sensory systems (vestibular, visual and somatosensory) used for postural control could be clearly assessed by using the power spectrum of the center of pressure (Giacomini et al. 1998; Palmieri et al. 2002). In this context, we also examined the influence of the temporal change in visual acuity due to contact lens insertion and removal (Uchiyama and Demura, 2007) and the influence of differences in the visual acuity of the naked eye (Uchiyama et al. 2006) on postural control during an upright standing posture using the spectrum of center of pressure (COP) sway. To examine the effect of temporal changes in visual acuity, the visual acuity of the same participant was varied by using contact lenses. To examine the effect of the visual acuity of the naked eye, the COP sway was measured in two unpaired groups with different visual acuities. We found that the changing pattern of the COP sway spectrum between visual field conditions differs according to differences in visual acuity (Uchiyama et al. 2006; Uchiyama and Demura, 2007). Namely, people with low visual acuity showed less change in the COP sway spectrum due to the change of visual field conditions com-

pared to people with high visual acuity. However, clinically, COP sway during an upright standing posture has to be comprehensively assessed from several viewpoints (Benvenuti, 2004). Although many parameters assessing various aspects of body sway have been proposed (Raymakers et al. 2005), Kitabayashi et al. (2003a) reported that the COP parameters proposed in previous studies can be summarized into the following 4 sway factors: sway velocity, antero-posterior sway, medio-lateral sway and sway frequency.

This study aimed to examine the role of central and peripheral vision during an upright standing posture in different visual acuity groups using the four COP sway factors.

MATERIALS AND METHODS

Participants

Eleven healthy males (age: 21.1 ± 2.0 yrs, height: 172.3 ± 3.6 cm, body weight: 66.0 ± 7.5 kg) and 15 healthy females (age: 22.2 ± 2.2 yrs, height: 159.1 ± 6.9 cm, body weight: 48.1 ± 5.2 kg) without a history of neuro-otological abnormalities or dizziness participated in this study. Participants with binocular visual acuity ranging from 0.4 to 0.9 were excluded from this study. The participants were then categorized into a high visual acuity group (above 1.0 binocular vision) and a low visual acuity group (below 0.3 binocular vision). The former group consisted of 4 males and 5 females (1.5 ± 0.0 and 1.4 ± 0.2 binocular vision, respectively), and the latter group consisted of 7 males and 10 females (0.2 ± 0.1 and 0.2 ± 0.1 binocular vision, respectively). The participants did not wear glasses or contact lenses for visual correction.

There was no significant difference in the physical characteristics of both groups (high visual acuity group: age 21.1 ± 1.3 yrs; height 164.3 ± 10.3 cm; body weight 56.92 ± 13.2 kg) (low visual acuity group: age 22.1 ± 2.4 yrs; height 164.9 ± 7.8 cm; body weight: 55.0 ± 9.2 kg). The subjects' physical characteristics were almost the same as the age-matched national standard value (Laboratory of Physical Education, Tokyo Metropolitan University, 2000). Before the measurements, the purpose and procedure of this study were explained in detail and informed consent was obtained.

Experimental conditions

Three visual-field conditions (no vision, central vision, and full vision condition) were generated with constricting the visual information from the central and peripheral visual fields. Visual fields were classified broadly into a central visual field (visual angle ≤ 2.5 degrees) and a peripheral visual field (visual angle ≥ 2.5 degrees) from the anatomical and functional differences of the retina (Margolis et al. 2002).

In the no vision condition, participants were asked to stand barefoot on a stabilometer in a completely dark room with their eyes open and their gaze fixed straight ahead. In the central vision condition, participants fixated on a low intensity red light (3 cm in diameter, visual angle: approximately 0.6 degrees) located 3 m in front of them at eye level in a dark room. In the full vision condition, participants fixated on a cross of red tape (tape width: 2 cm) placed on a black wall 3 m in front of them in a bright room (Amblard and Carblanc, 1980; Okuzumi et al. 1996). The red tape was extended to the outside of the visual field of the participants. In other words, the piece of tape which ran at the gaze point lengthwise was put from the foot of the participant to the ceiling above their head, and the piece of tape which ran at the gaze point sideways was put from their back left to their back right. Before beginning the measurement of each visual field condition, a dark/light adaptation period of 10 min was performed in the actual measurement room. In consideration of an order effect, the trial order of each visual field condition was assigned at random using a random table. The participated subjects of both visual acuity groups participated in all visual field condition tests.

Measurements of visual acuity

Binocular visual acuity, the spatial resolving capacity of the visual system, was measured using an apparatus for eyesight tests (SS-3 Screenoscope, Topcon, Japan). Participants sat on a chair in front of the apparatus and binocularly viewed the character "E". A tester pointed to the "E" in descending order of letter size and varying orientation and recorded the visual acuity depending on the smallest size that participants could correctly identify.

Measurement of visual angle

To assess participants' visual field size, eight visual angles (upside superolateral, outside, inferolateral, down-side, inferomedial, inside, and superomedial) in both eyes were measured using a manual diopsimeter by

circular measure (HE-138, HANDAYA CO., Japan). The tester moved a white target (1 cm in diameter) from the edge to the central point of the diopsimeter. Participants gave the tester a cue when the target came into their visual fields, and the tester recorded the angle at that time.

Measurements of postural sway

Postural sway of each participant was assessed as center of pressure (COP). A stabilometer (G5500, Anima, Japan) was used for COP measurements. This instrument can calculate the COP of vertical loads from the values of three vertical load sensors placed on the corners of an isosceles triangle on a level surface. Data were sampled at 20.0 Hz and transferred to a personal computer following A/D conversion.

COP measurement was carried out in accordance with the standard procedure of the Committee for Standardization of Stabilometric Methods and Presentation (Kapteyn et al. 1983). Participants stood on a foot-print painted on the stabilometer with their heels together and their arms hanging loosely by their sides. Each participant practiced the COP measurement once in each visual field condition prior to the following two trials for further analysis. COP was measured for 1 min in each trial after the participant became stable. Between trials, the subjects were allowed to rest in a sitting position for about 1 min, and fatigue was never an issue. Their feet position on the stabilometer was marked with a pen. If the participants moved between trials, they were asked to return to the original position.

Parameters

Demura et al. (2001) and Kitabayashi et al. (2003b) identified 114 kinds of COP sway parameters that have been proposed as indices of postural sway and narrowed them down to 34 parameters withing 7 domains (path length, area, velocity, amplitude distribution, spectrum and vector) from the viewpoint of logical validity and trial-to-trial reliability. Kitabayashi et al. (2003a) applied factor analysis to a correlation matrix consisting of the above-stated 34 parameters obtained from 220 young adults and identified four critical COP sway factors: sway velocity, antero-posterior sway, medio-lateral sway, and high frequency sway. In this study, we selected these four sway factors as evaluation parameters of COP sway. Factor scores of the 4 sway factors were calculated by using the values of the 34 sway parameters and the sway factor score coefficients calculated by Kitabayashi et al.

(2003a). These scores were then used for evaluating the participants' postural sway. By using these 4 sway factors, each participant's overall postural sway characteristics could be assessed without the need to assess the separate COP sway parameters used in various previous studies.

Each factor score, which is standardized by a z-score, has no unit. Factor scores were interpreted as follows; the higher each factor score, the more clearly the sway is defined by the sway factor's characteristic (e.g. a high factor score for "sway velocity" means that the COP sway is fast). The factor "high frequency sway" has a higher value when COP sway contains a greater percentage of high frequency components (over 2.0 Hz) and contains a lesser percentage of low frequency components (from 0.02 to 2.0 Hz).

Furthermore, because scores were standardized by a z-score, the values of the sway factor score can be either positive or negative; however, when interpreting the results of factor scores, there is no need to consider the positive and negative signs.

Statistical analysis

The mean differences of participants' physical characteristics between visual acuity groups were examined by unpaired t-test. The effect of visual acuity group and gender on visual acuity and visual field angle was examined using five separate two-way (visual acuity X gender) analyses of variance (ANOVA). If ANOVA indicated a significant interaction, Tukey's honestly significant difference (HSD) test was used to test the differences between cell means.

Posture related COP data were analyzed using 4 separate mixed-factor ANOVA. This analysis examined the effect of the visual acuity group factor (low and high visual acuity group) and the visual field condition factor (three levels with repeated measures: no-vision, central vision and full vision). If ANOVA indicated a significant interaction, Tukey's HSD test was used to test differences between cell means. If a significant main effect was found in the visual field condition, the mean difference between visual field conditions was tested by using Tukey's HSD test.

RESULTS

Characteristics of participants' physique and visual function

No significant difference was found for any of the participant's measured physical characteris-

TABLE 1. The results of two-way ANOVA (visual acuity \times gender) for visual acuity and visual field angle

Factor A (visual acuity)	High				Low				Two way ANOVA, F-value		
	Male (<i>n</i> = 4)		Female (<i>n</i> = 5)		Male (<i>n</i> = 7)		Female (<i>n</i> = 10)		FA	FB	IA
	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
Left visual acuity	1.50	0.00	1.24	0.22	0.17	0.09	0.12	0.09	497.99*	8.06*	0.38
Right visual acuity	1.50	0.00	1.38	0.15	0.17	0.10	0.11	0.08	853.26*	4.16	2.29
Binocular visual acuity	1.50	0.00	1.38	0.15	0.16	0.07	0.17	0.10	840.71*	1.48	0.11
Left mean visual field angle	70.53	3.57	69.58	2.12	69.36	2.72	69.94	5.34	0.05	0.01	0.18
Right mean visual field angle	70.44	3.14	68.58	2.78	69.88	3.87	70.86	3.98	0.28	0.07	0.76

*: $p < 0.05$; FA, factor of visual acuity; FB, factor of gender; IA, inter-action; High, high visual acuity group; Low, low visual acuity group. Mean visual field angle of each eye was calculated by deviding a total angle of 8 visual fields deviding by 8 (the number of visual field directions).

tics between visual acuity groups (age: $t = -1.05$, $df = 24$, $p = 0.31$; height: $t = -0.17$, $df = 24$, $p = 0.87$; body weight: $t = 0.42$, $df = 24$, $p = 0.68$). Table 1 shows the results of two-way ANOVA for visual acuity and visual angle. No significant interaction was found for any parameter. A significant main effect of the visual acuity group was found for the visual acuity of the left eye ($F(1, 22) = 497.99$, $p = 0.001$), right eye ($F(1, 22) = 853.26$, $p = 0.001$), and both eyes ($F(1, 22) = 840.71$, $p = 0.001$). A significant main effect of gender was found only in the visual acuity of the left eye ($F(1, 22) = 8.06$, $p = 0.009$) but not in the visual acuity of both eyes, which was used as the criteria for visual acuity grouping. Hence, further analyses were done with pooled gender data.

Influence of visual acuity and visual field condition on COP sway factors

Fig. 1 shows the results of two-way ANOVA (visual acuity group \times visual field conditions) for the COP sway factors. A significant interaction was found in antero-posterior sway ($F(2, 48) = 3.49$, $p = 0.039$) and high frequency sway ($F(2, 48) = 3.58$, $p = 0.036$). The antero-posterior sway of the low visual acuity group was significantly larger in the no vision condition than in the full vision condition. Furthermore, the antero-posterior sway of the low visual acuity group was significantly smaller than that of the high visual acuity

group in the full vision condition. The high frequency sway of the low visual acuity group was significantly smaller than that of the high visual acuity group in the no vision and central vision conditions. A significant main effect of visual field condition was found on sway velocity ($F(2, 48) = 17.87$, $p = 0.001$). The sway velocity of both visual acuity groups increased with decreasing visual field area. A significant main effect of the visual acuity group was not found for any parameter (sway velocity: $F(1, 24) = 2.74$, $p = 0.11$; antero-posterior sway: $F(1, 24) = 1.21$, $p = 0.28$; medio-lateral sway: $F(1, 24) = 1.52$, $p = 0.23$; high frequency sway: $F(1, 24) = 4.09$, $p = 0.05$). Medio-lateral sway did not significantly change, regardless of the difference in visual acuity or changes in visual field conditions (visual acuity: $F(1, 24) = 1.52$, $p = 0.229$; visual field conditions: $F(2, 48) = 0.07$, $p = 0.935$; interaction: $F(2, 48) = 3.13$, $p = 0.053$).

DISCUSSION

Different visual acuity groups were established to examine the influence of visual acuity level on upright postural sway. This study stratified participants into high and low visual acuity groups based on uncorrected binocular visual acuity (Ishizaki et al. 1995). As a result, it was confirmed that mean binocular visual acuity in the high visual acuity group was 1.5 in males and 1.4

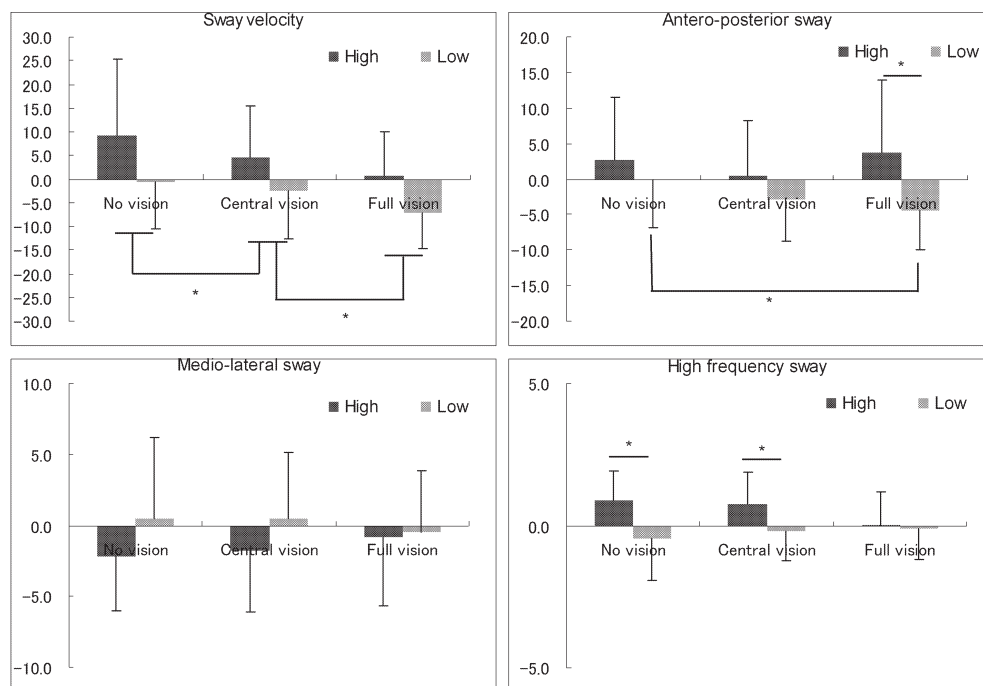


Fig. 1. The COP sway (velocity, antero-posterior sway, medio-lateral sway, and sway frequency) of both visual acuity groups in each visual field condition.

■: high visual acuity group; ■: low visual acuity group; *: $P < 0.05$.

These 4 parameters of COP sway (velocity, antero-posterior sway, medio-lateral sway, and high frequency sway) were calculated as factor scores of the four factor scores of COP sway proposed by Kitabayahsi et al. (2003a). Each parameter is standardized by a z-score. Thus, when interpreting the results of factor scores, there is no need to consider the positive and negative signs.

in females, while the acuity was 0.2 in both males and females in the low visual acuity group. Both groups were classified into normal visual acuity (above 1.0) and low visual acuity (below 0.3) groups based on the criterion for measurement of visual acuity (Li 2001). Furthermore, there was no difference in the visual angle between both visual acuity groups. Hence, we judged that it was not necessary to consider the visual field size when examining the influence of visual acuity on postural control. Bergman and Sjostrand (1992) also reported that visual acuity does not influence the visual angle. However, we also cannot deny the possibility that there are differences in some functions outside of the visual system between the two groups. In other words, there may be a difference in postural control characteristics due to factors other than the superiority or inferiority of the visual system. Therefore, it is necessary to consider the following limits when interpreting

the present results (the difference in postural control characteristic between visual acuity groups). A direct comparison of sway factors between both visual acuity groups in each visual field condition is undesirable. It is not the differences of sway factors in each visual field condition between the visual acuity groups, but rather the difference in the changing pattern between the visual field conditions, that affects the difference in sway characteristics between the visual acuity groups.

An interesting finding in this study was that the difference in visual acuity influenced antero-posterior sway and high frequency sway. This suggests the need to consider the visual acuity when examining the previously mentioned three theories regarding the role of central and peripheral vision in postural control, as summarized by Bardy et al. (1999).

Sway velocity in both visual acuity groups became significantly higher with restriction of

visual information. It is inferred that people can stabilize posture during an upright standing posture by using visual information within 2.5 degrees of the central visual field, because both groups' sway velocity decreased in the central vision condition compared with the no vision condition. Berencsi et al. (2005) and Wada and Sasaki (1990) reported that the COP sway area became smaller when visual information was presented in the central visual field compared with no visual information, although neither measured sway velocity. Further, Turano et al. (1996) compared COP sway between patients with central visual field loss and normal controls when presenting static visual stimulation plus somesthetic interference stimulation to alter the participants' somatosensory feedback, and they reported that the COP was larger in the participants with a field loss. Given these findings, it is inferred that, with regard to sway velocity, spatially fixed visual information in the central visual field contributes to postural stabilization regardless of the level of visual acuity. Furthermore, peripheral vision may be dominant for postural stabilization compared to central vision, because sway velocity was higher in the central vision condition than in the full vision condition.

Although there was no significant difference in medio-lateral sway, the antero-posterior sway in the low visual acuity group was smaller in the full vision condition than in the no vision condition. In contrast, participants with high visual acuity showed no change in either antero-posterior or medio-lateral sway in spite of the changes in the visual field condition. This result is not consistent with our hypothesis.

It is difficult to explain why the amount of antero-posterior sway of the participants with high visual acuity did not change between visual field conditions from this data. Increases or decreases of the antero-posterior sway may not always mean that the actual COP sway amplitude or length is larger or smaller. It is also possible that the sway component in the specific frequency band increases or decreases. The increase and decrease of various frequency components may occur at the same time, such that when presenting

the peripheral visual input to the participant with high visual acuity, wiggle and short cycle sway (generally understood as COP sway) decrease, while very long cycle (from 10 to dozens of seconds) COP sway increases.

In our previous study (Uchiyama et al. 2006), we reported on the frequency analysis result that explains the present results; the antero-posterior sway component of 0.1-1.0 Hz increased in the participants with low visual acuity when their visual field was limited. On the other hand, the power of the antero-posterior COP sway spectrum in the full vision condition of the participants with high visual acuity was small for 0.1-1.0 Hz and large for equal to or less than 0.1 Hz. In contrast, in the no vision and central vision conditions, the power of 0.1-1.0 Hz was large and the power equal to or less than 0.1 Hz was small. From these results, it was inferred that in people with high visual acuity, relatively high frequency sway (0.1-1.0 Hz) increases when their peripheral visual field is largely limited (similarly to the no vision and central vision conditions). Conversely, when peripheral visual input is given (similarly to the full vision condition), the sway in the frequency band decreases; concurrently, the low frequency sway (that below 0.1 Hz) increases. In other words, the total power of the sway is smaller in the central vision condition than in the no vision condition in both visual acuity groups. However, in the full vision condition, a different tendency may be found between the low and high visual acuity groups. Considering Parseval's identity (that the sum of the signal energy in the time domain and the sum of the signal energy in the frequency domain is equal), it is inferred that the size of the amplitude of the antero-posterior COP sway of the people with high visual acuity in the full vision condition was as large as that in the no-vision condition and that they have lower frequency and more unstrained sway than people with low visual acuity.

Therefore, in the present results, the amount of antero-posterior sway of participants with high visual acuity appeared not to be controlled between visual field conditions. This may be because participants with high visual acuity showed

large and low frequency sway in the full vision condition, unlike participants with low visual acuity. However, it is difficult to definitively explain from the present data why the low frequency components equal to or less than 0.1 Hz increased by the presentation of peripheral visual input. In addition, there is no report that has examined the relationship between peripheral vision and such low frequency sway components until now. It is necessary for us to deepen our examination of this problem in the future.

Furthermore, although Wada and Sasaki (1990) and Ishihara et al. (2005) did not consider participants' visual acuity, they reported that the antero-posterior sway amplitude became larger than the medio-lateral sway when the visual field was limited. Given these findings, it is inferred that a decrease in visual acuity or reduced visual information due to restricted visual fields more markedly influences postural control of antero-posterior sway than medio-lateral sway. Similar to reports that labyrinthine deficits may cause medio-lateral destabilization (Giacomini et al. 1998), postural control mediated by the visual system may also have a directional specificity.

Moreover, under the restricted visual fields conditions (no vision and central vision), participants with normal visual acuity showed greater high frequency sway than participants with low visual acuity. However, this parameter of "high frequency sway" used in this study refers to the percentage of spectral components over 2.0 Hz in the total spectral power of COP sway. In other words, the differences in high frequency sway found between visual acuity groups is discussed as differences of the percentage, not as differences of the absolute amount of spectral power at high frequency, between visual acuity groups. Therefore, from this result it is inferred that the degree of difference in the spectral distribution pattern in the no vision and central vision conditions is larger in high visual acuity people than in low visual acuity people. As stated above, in our previous paper (Uchiyama et al. 2006), high visual acuity participants had a very large power below 0.1 Hz in the full vision condition compared with the no vision and central vision conditions. This phe-

nomenon was not found in participants with low visual acuity (Uchiyama et al. 2006). The results for the factor of "high frequency sway" in this study are considered to reflect these phenomena. Further examination is needed to reveal the reason for the increased low frequency power of the high visual acuity people in the full vision condition. Zangaladze et al. (1999) inferred that the somatosensory system works well as a compensatory process for people with visual impairments. Namely, high frequency sway may have shown little difference between visual field conditions, because postural control by the somatosensory system works well in the participants with low visual acuity.

CONCLUSION

In summary, regardless of the level of visual acuity, the COP sway velocity during an upright standing posture becomes higher with restriction of the visual field. In other words, both central and peripheral visions play an important role in postural stabilization. In contrast, the magnitude of antero-posterior sway and the sway spectrum differ depending on visual acuity. Hence, consideration of the visual acuity may be necessary in examining the role of vision in postural control.

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