The purpose of this study is to suggest a numerical model for postural control ability variations in children, young adults and the elderlies. Three sensors were attached to the subjects’ bodies at the vertex, the iliospinale and the mid-patellar to measure three-dimensional acceleration at each point while subjects maintained a standing posture for two minutes. Variations in acceleration at the vertex differed among the three age groups. Most children subjects could not maintain the initial position during the trials, whereas the young adult subjects could maintain it. Most elderly subjects could maintain their lateral balance however it was difficult for them to maintain their anteroposterior balance. From the results of acceleration measurement, it is indicated that the scalar of the average acceleration vector at the vertex point could serve as a numerical criterion of postural control ability.

**Key words:** postural control; children; young adults; elderlies and physical ability

**INTRODUCTION**

The physical ability of children grows until they become adults (Suzuki et al., 1998; Kuh et al., 2006; Sparto et al., 2006). However, it declines with aging after full development has been achieved. This decline in physical ability may increase the risk of falling accidents. In an aging society, it is important to ensure the health and safety of the elderlies while they are performing daily activities. Many fatalities and injuries, including falling accidents, occur among the elderlies (MHLW, 2010). One of the reasons for falling accidents is the decline of postural control ability.

The force-plate method has been used to measure balance in several clinical investigations (Chaudhry et al., 2004; Carpenter et al., 2006). This method has also been used to evaluate postural control ability differences among generations in relation to floor oscillation (Fujiwara et al., 2007; Fujiwara et al., 2011). Acceleration sensors have also been used to measure human activity, especially in the evaluation of patient rehabilitation (Similä et al., 2006; Nishi et al., 2006). Although the force-plate method is used very frequently to measure postural control ability, it is limited to indoor use. Acceleration measurement, on the other hand, can be performed anywhere. Thus, the establishment of criteria for postural control ability by means of acceleration measurement will be beneficial.

Previous studies have compared postural control ability in children and young adults using acceleration measurement (Kato et al., 2008; Yeoh et al., 2008). There are differences in postural control ability among the elderlies who are prone to daily falls in their daily life and those who are not (Ostrowska et al., 2008). In addition, their average ability to maintain good posture is lower compared with that of younger adults.

This study evaluates the ability of people in three different age groups (children, young adults and the elderlies) to maintain their posture in an experimental situation. The purpose of this study is to identify evaluation criteria for postural control ability by measuring acceleration variations while maintaining the standing posture among the three age groups.
METHODS

Eight elderly subjects were enrolled in this study (males: 4, females: 4; average age (+/-SD): 70.9 +/-6.6 years; height: 161.5 +/-9.9 cm; weight: 60.1 +/-7.5 kg). Thirteen subjects were children (males: 6, females: 7; average age: 7.5 +/-1.0 years; height: 122.7 +/-6.7 cm; weight: 24.4 +/-3.5 kg). Eleven young adults also participated (all female; average age: 20.0 +/-0.0 years; height: 157.9 +/-5.1 cm; weight: 51.5 +/-6.2 kg).

Three acceleration sensors (AS-5TG acceleration transducer; Kyowa, Tokyo, Japan) were attached to three body points: the vertex (upper body measurement point), the iliospinale (center body measurement point), and the mid-patellar (lower body measurement point; the back of the knee joint at a plane parallel to the middle of the patella). The sensors measured three-dimensional acceleration at each point. Figure 1 displays the experimental set-up. As displayed in the figure, the sensor at the vertex point was fixed on a cap at the farthest point from the floor. The sensor at the iliospinale point was fixed on a belt tied at the waist. The sensor at the mid-patellar point was attached with a rubber band to the back of the knee, which is a joint that influences posture control ability.

Subjects were instructed to maintain an upright standing posture with the arms by their sides for 2 minutes under two conditions, eyes open and closed. They were also instructed to keep their feet close and set to the anterior direction without footwear. When they open their eyes, they were instructed to look at the target point at a distance of 2m. Lateral and anteroposterior accelerations were measured at a 200-Hz sampling speed with an amplifier (EDS400A; Kyowa). Two criteria were evaluated on the basis of variations in acceleration: (1) the scalar of the average acceleration vector (DST) and (2) the area of the ellipse whose x-axis was the SD of the lateral acceleration and whose y-axis was the SD of the anteroposterior acceleration (ELP). The average DST and ELP values for each age group were compared with those of the other groups in both conditions. All measurements were calculated by ANOVA and Fisher’s post-hoc analysis.

RESULTS

Acceleration in anteroposterior and lateral directions

Table 1 indicates the average values of acceleration and SD at each measurement point. For lateral acceleration, positive values indicate swaying toward the right side and negative values indicate swaying toward the left side. Positive values in the anteroposterior direction indicate swaying...
forward and negative values indicate swaying backward. The average lateral acceleration at the vertex in the elderly subjects was 0.25m/s², which was the largest value among the three groups. SD of the lateral acceleration at the vertex for the children subjects in the eyes open condition was 0.60 m/s² and that in the eyes closed condition was 0.81m/s². Therefore, the largest value for this parameter was found in the children group. The average anteroposterior acceleration at the vertex in the elderly subjects in the eyes open condition was 0.64m/s² (SD=0.98 m/s²). The average value of this parameter in the children subjects was lower than that in the elderly subjects. SD for anteroposterior acceleration at the vertex in the children in the eyes closed condition was 1.28m/s², which was the largest value for this parameter among the three groups. The average values at the vertex in both directions under both eyes conditions in the young adults were lower than those in the other groups. The values at the vertex point in the young adults for both lateral and anteroposterior acceleration in both eye conditions were similar. The values at the vertex in the other groups for anteroposterior acceleration were larger than those for lateral acceleration. The average values (+/- SD) in the children and the elderly subjects at the iliospinale were lower than those at the vertex. The differences in the values in the two directions in all the groups at the iliospinale were also lower than those at the vertex. The average acceleration in the anteroposterior direction for the young adults in the eyes open condition at the iliospinale was −0.07m/s² and that at the vertex was −0.05m/s². The average acceleration in the lateral direction for the young adults in the eyes open condition at the mid-patellar point was lower than those for the other groups (0.03m/s²). The value in the anteroposterior direction for the elderly subjects in the eyes closed condition at the mid-patellar point was lower than those in the other groups (-0.03m/s²).

<table>
<thead>
<tr>
<th>direction</th>
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<th>vertex</th>
<th>iliospinale</th>
<th>mid-patellar</th>
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<td>eyes opened</td>
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<td>0.08</td>
<td>-0.07</td>
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<td></td>
<td>SD</td>
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<td>0.20</td>
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<tr>
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<tr>
<td></td>
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<tr>
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<tr>
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<tr>
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</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.98</td>
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</table>

The average value of acceleration at all the three points in the elderly subjects in the eyes open condition was −0.26m/s². The average SD of acceleration at all the three points in the children in the eyes closed condition was the largest among the three groups (0.45m/s²). The differences between values at the iliospinale and the mid-patellar point were lower than those between values at the vertex and the iliospinale. Statistical analysis indicated that only acceleration in the anteroposterior direction at the vertex in the eyes open condition in the elderly subjects was significantly different from that in the other groups (F=3.96, df=2, p<0.05).

Figure 2 indicates the examples of variation in acceleration at the vertex point in the eyes closed condition. Maximum movement range in the child subject varied in the lateral and anterior directions by approximately 3m/s², whereas the variation in the posterior direction was >4m/s². These values are higher than those in the other two subjects. Moreover, the values for the young adult and the elderly subject were relatively stable. They varied from −1 to 1m/s² in the lateral direction, and from −1 to 2 m/s² in the anteroposterior direction. However, the differences in the anteroposterior acceleration between the elderly subject and the young adult indicated a range of 0 to −3 m/s².
Average acceleration from the initial position (DST) and the area of the ellipse (ELP)

The two criteria to explain variations in acceleration can be used from the result: DST and ELP. These criteria outline the values for these parameters in each group, which were larger at higher points.

Figure 3 indicates the average values (+/-SD) for movements at each subject’s vertex point. Individual differences in values for the children group were larger than those for the other groups in terms of both direction and amount. Individual differences in SD for each subject values were also indicated in the children group for both directions. Except two elderly subjects, DST for the young adults and the elderly subjects was smaller than that for children. ELP for the young adults and the elderly subjects was also smaller than that for children. Figure 4 indicates the average values for movements at each subject’s iliospinale point. There are individual differences among the subjects for all groups in terms of anteroposterior direction. However, there are few differences in values for all groups in terms of lateral direction. Figure 5 indicates the average values for movements at each subject’s mid-patellar point. Individual difference among the young adults group and the elderly group are smaller than the other measurement points. Average acceleration of the children group is larger than the other two groups.

Figure 6 displays the statistical results for DST. At the vertex point, in the eyes open condition, there were significant differences between the values for the children and the young adults (t=2.21, df=2, p<0.05) as well as those between the young adults and the elderly subjects (t=2.58, df=2, p<0.05). Significant differences were also observed between the values for the children and the young adults (t=4.50, df=2, p<0.01) in the eyes closed condition, as well as those between the young adults and the elderly subjects (t=2.23, df=2, p<0.05). At the iliospinale point, in the eyes open condition, significant difference was indicated only between the values for the young adults and the elderly subjects (t=2.07, df=2, p<0.05). Differences between the values for the children and elderly are not significant. In eyes closed condition, there are significant differences between the values for the children and the elderly (t=2.24, df=2, p<0.05), as well as the difference between the values for the young adults and the elderly (t=2.97, df=2, p<0.01). Significant differences at the mid-patellar point were not indicated in both of the eyes conditions. In the eyes closed condition, significant difference was indicated for the mid-patellar point only between the values for the children and young adults (t=2.33, df=2, p<0.05).

Figure 7 displays the statistical results for ELP. At the vertex point in the eyes open condition, ELP of the children group is significantly different from those in the other groups (F=16.0, df=2, p<0.01). That in the eyes closed condition is also significantly different (F=12.8, df=2, p<0.01). At the iliospinale point, a significant difference was not observed in the eyes open condition. In the eyes closed condition, there are significant difference for the iliospinale point between the values for the children and the young adults (t=2.24, df=2, p<0.05), as well as the difference between the values for the children and the elderly subjects (t=2.25, df=2, p<0.05). At the mid-patellar point, significant differences in ELP were not noted in both of the eyes conditions.
Acceleration values in anteroposterior and lateral directions

Values for acceleration at the vertex point in all groups were notably higher than those at the other points. The mean and SD values appear to be similar. The mean and SD values for acceleration in all the groups in both directions at the mid-patellar point were lower than those at the other points. An exception is seen in the anteroposterior direction at the mid-patellar point in the eyes closed condition in the young adults. Figure 3-5 indicates differences among all the groups and all the measurement points. The vertex point, the highest point in the body, can be affected by movements of all the human body (Fig. 3). Only small movement at the mid-patellar (Fig. 5) may move upper parts of the body by the radical posture keeping ability. Especially a physical task to maintain standing

DISCUSSION
posture is not easy for the children and elderly, because they do not have physical ability as in the case of the young adults. In general, the values at the higher measurement points on the body were larger, except in the young adults. Differences among individuals were larger in the children and the elderly subjects than in the young adults. Values for variation in acceleration indicate differences in postural control ability. Thus, simple criteria such as DST and ELP seem to be practical in the evaluation of postural control ability.

**Average acceleration values from the initial position**

DST indicates each subject’s tendency to maintain a stable posture. The average DST in the children group varied more widely than that in the other groups. The average DST in the elderly subjects varied slightly more than that in the young adult subjects. The trend in DST and that in ELP in the children group was similar. On the other hand, ELP in the elderly subjects was similar to that in the young adults. Most children could not keep their balance at the initial position of the experiment. On the other hand, most of the young adults and the elderly subjects (except 2) were able to maintain their initial posture. The results for children in a past study (Kato, 2009) were similar to those in this study. This tendency (Fig. 3) is especially notable at the vertex point. Children may not be able to maintain balance because their muscle function is not sufficiently developed. In addition, individual differences among children are large even if the difference in their age is small. Height may therefore also be used as a criterion for growth function when in children of the same age.

**Differences of the evaluation value among the measurement points and the age groups**

Muscles and statoreceptors aid in maintaining posture. Differences in these factors may explain differences in acceleration variations in this study. Maintaining a stable position at the mid-patellar point may be easier than at the other points because it is closer to the floor. This is because the range of movement of the knee is limited when a person in standing on both feet, resulting in low acceleration. Differences among the groups at the mid-patellar point were minimal. On the other hand, an individual height is the same as the distance from the floor to the vertex. Thus, the range of
movement is larger at the vertex point compared with the other two points. Individuals use muscles and statoreceptors in the upper and lower body to maintain their posture. However, children and the elderlies lack ability than young adults because of inadequate physical development (children) and physical decline (the elderlies). In this study, this was evident in both open and closed eyes conditions, except at the mid-patellar point in the children.

Variation in acceleration values in the children group at the mid-patellar point was larger than that at the iliopspinate point because maintaining posture for 2 minutes is not an easy task for the children. Most of them were restless during the experiment. This was reflected markedly at the mid-patellar point. Because movements at the mid-patellar point require different mechanisms in different age groups, measurement at this point is not suitable as a criterion to evaluate postural control ability. Variation at the iliopspinate point was minimal among the groups. Thus it is not also a suitable point for the measurement of acceleration. Therefore, measurement of variations in acceleration at the vertex point is most appropriate as a criterion of the ability to maintain an upright posture.

The example in Fig. 3 shows that variations in acceleration at the vertex point clearly indicate differences in the ability to maintain an upright posture. The average values for acceleration in the young adults and elderly subjects during the 2 minutes experiment were close to those in the initial position. However, the average values for the children subjects were variable because their physical development was incomplete. In addition, differences among individuals within groups were observed in the results. The distribution of values in the elderly subjects indicates that their upper bodies have a tendency to lean forward because of the decline of strength in the erector spinae by aging. These data in this study suggests that postural control ability can be evaluated and quantified by measuring variations in acceleration from an initial position. The acceleration variation at the vertex point in the eyes closed condition was the most valuable evaluation criterion in this study. Two other criteria were used to quantify differences in variation of acceleration: DST and ELP (Fig. 6 and Fig. 7). This study found that DST expresses differences between age groups more concretely than ELP.

CONCLUSION

Acceleration of certain points on the body can be used to measure the ability to maintain balance in a standing position. The acceleration variation at the vertex point is the best indicator of differences among age groups to measure postural control and balance. The measurement method and criteria examined in this study will be practical to evaluate the development and maintenance of posture control ability and to plan rehabilitation programs. In the future, acceleration data of subjects of middle age (30–40 years) are necessary to complete the numerical model developed in this study.

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References


