The relation between the perception of affordances and actual motor performance on the maximum height in stepping-over task in aging

Masahiro Ogawa[1,*], Koji Yamato[2], Hideki Miyaguchi[1] and Tsuneji Murakami[1]

Key words：1. perception of affordances　2. step over　3. aging adults

The purpose of this study is to examine the difference between perception of affordances and motor performance in young adults (in their 20s) and aging adults (in their 60s, 70s and 80s). In the first experiment, to determine the distance which would be used in the second experiment, we examined how viewing distances affected the perception of affordances on a stepping-over task. As a result, we found that a 4 meter distance was suitable for the following experiment. In the second experiment, we compared, in young adults and aging adults, the perceived maximum height to the actual maximum height of a bar which the subjects could step over. We found that for the stepping-over task the perception of affordances did not show a generational difference, while the actual motor performance did. In particular, aging adults older than 80 years showed this difference more clearly. This suggests that if young adults can estimate their motor performance precisely, then motor perceptual ability progressively declines in aging.

Introduction

The ability to move safely throughout the world is not the result of motor performance* alone; perceptual sensitivity to the surrounding environment is also critical[1]. Haptic, auditory, and visual sources of information all play a role in guiding our actions[2]. For example, vision is useful in choosing the most appropriate mode of locomotion, depending upon properties of the ground surface, and in picking the path around obstacles to be taken. Successful action is a simultaneous function of perceptual sensitivities and motor capabilities. One example of this type of inter-relation between perception and action systems is seen in the concept of affordances. Gibson[3] defined affordances as being what the environment offers an observer with reference to his or her action capabilities.

Several studies have examined actor-environmental fit between perception of affordances* and actual motor performance by comparing perceived to actual maximum (critical) motion of subjects climbing obstructions without using their hands[4,5], walking through apertures[6], and stepping over obstructions[7]. Experimental investigations of young adults' perceptions about the affordances of various actions, such as climbing stairs and stepping over obstructions, have revealed two main findings. First, perceptual judgments are categorical: once a critical point has been reached, judgments of capabilities change from "able" to "unable". Second, perceptual judgments of capabilities are related to actual action capabilities, with relatively accurate perceptual assessments of motor capabilities.

However, the subjects in these studies were nearly all young adults. A few attempts have been made regarding these relationships as affected by aging. Konczak et al.[5] studied the difference between the highest stair reached when both young adults and aging adults could climb without using their hands. Moreover, they compared the highest stair which the subjects estimated, with the highest one which they could actually climb. The result indicated no statistical difference between the perception of affordance and the actual motor performance of younger adults, or of aging adults.

There have been some studies that used other

・高齢者における跨ぎ動作のアフォーダンス知覚と実際のパフォーマンスの関係

・1）Graduate School of Health Sciences, Hiroshima University（広島大学大学院保健学研究科）
　2）Department of Rehabilitation, Hiroshima University Hospital（広島大学病院リハビリテーション部）
・＊連絡先：〒 734-8551 広島市南区霞 1-2-3　広島大学大学院保健学研究科
　　　　TEL & FAX　+82-257-5443　E-mail : masa-ogawa@hiroshima-u.ac.jp

・広島大学保健学ジャーナル　Vol. 7 (2)：43～50，2008

methods to compare perceiving ability to actual performance. The estimated duration to complete motor movement is highly correlated with the duration necessary to actually perform the same movement in young subjects[8-10]. Skoura et al.[11] examined the temporal features of estimated and actual action as a function of aging through a pointing task which included a range of difficulties. In this study, they observed that actual motor performance of only the complex task deteriorated, while motor perception* remained unchanged in old age (70s). This result showed that some particularly complex and difficult motor actions perturbed the excellent congruence of motor performance and motor perception in aging adults.

It is clear that if the difficulty and the complexity of the task affect motor performance and perception of affordances, then the motor performance of aging adults older than 80 years may differ more from their motor perception. A more demanding motor performance for aging adults older than 80 years may be all the more impaired. On the other hand, the changing of perception of affordances remains unknown.

Given the above-mentioned observations, the goal of this study was to examine the difference between the perception of affordances and the motor performance of aging adults in their 60s, 70s and 80s, and young adults in their 20s. The task used in this experiment was stepping over a bar, the height of which is changeable. One of the main reasons why this task of stepping over a bar was chosen is that this movement needs sophisticated balance ability, and is easily hampered by aging[12,13]. We hypothesized that the actual motor performance would deteriorate in the stepping-over task, while the perception of affordances would remain unchanged in aging adults older than 80 years.

However, in order to know perception of affordances about height, it is necessary to determine the viewing distance* between subjects and task. Mark et al.[7] studied subjects who were asked to make judgments about the perceived maximum seat height at which they could sit, and the perceived maximum height they could climb, for five different distances. For each subject and each task, results showed that perception of affordances decreased monotonically as the subjects went farther away. Therefore, perception of affordances in the stepping-over task may be changed by the viewing distance.

Two experiments were conducted in this report. In Experiment 1, the effects of various measurement distances on perception of affordance for a stepping-over task were examined. Experiment 2 tested the difference between the perception of affordance and the motor performance of aging adults and young adults.

Word definitions in this study

* Motor performance is to execute a planned motion and to express it as an action.
* Perception of affordance is defined as an action boundary, that is, a phase transition beyond which a change in behavior, “possible” or “impossible” must take place.
* Motor perception is the internal movement which is perceived in the mind without actual physical movement.
* Viewing distance is the distance between the point at which the subjects are standing and the measurement instrument of the given task.

Experiment 1

Features of Perception of Affordances with Viewing Distance

The first experiment has its origins which suggest that observers tend to underestimate their perception of affordances as their viewing distance increases from the place at which they are looking[7]. The previous study used the height subjects were able to climb without using their hands and to sit down as the tasks. The aim of the first experiment was to examine the effect of viewing distance on perceiving affordances for the stepping-over task.

Methods

Subjects

The first experiment involved 10 young adults (3 female, 7 male). Average age was 22.5 (SD = 1.1) years old. The subjects were students in Hiroshima University or Graduate School of Hiroshima University. All subjects were in good health with healthy vision and without any nervous, muscular, or cognitive disorder. An examiner explained to all participants about the measurements and privacy policy and they signed consent forms. Approval for this study was obtained from institutional (Graduate School of Health Sciences, Hiroshima University) review board.

Equipments

Measurements were performed by using a bar, the height of which could be changed. The bar was supported by two poles. The bar and two poles were each painted in black and white. The length and thickness of the bar was 180 cm × 0.6 cm. Both of the poles were the same shape, 106 cm high and 3 cm wide. On each pole nails were driven in at 1 cm intervals in the range from 10 to 105 cm off the floor. A 4.8 m width × 2.0 m height white screen was suspended from the ceiling, 1 m away behind the bar.

Procedures

1) Perceived Height (PH)

PH was obtained for four distances (1 m, 2 m, 4 m and 8 m). Measurement order of different distances was randomized by means of a table of random numbers. At each distance, subjects judged if they could step over the bar without using their hands, or not. At first, the heights of the bar were changed by 5 cm intervals between 50 cm and 100 cm in random order, at four viewing distances. In the next step, we examined 1 cm intervals between the highest height they estimated to step over and the lowest height they estimated not to. If the border of "able to step over" or "not able to step over" was not a definite answer, the subjects would estimate again the unsure height until a clear answer was obtained. As a result, the highest height they estimated was regarded as PH.

Before measurements were taken, the subjects were instructed to "Please answer if you can step over the bar in front of you or not. Please, imagine stepping over it as just stepping over without using your hands or jumping when you step over." Moreover, they were also informed of the following three points: (1) to close their eyes when the examiner moves the bar, (2) to keep standing without moving their bodies during measurements, and (3) not to compare the height of the bar with something surrounding it. The examiner hid behind the screen during the judgment in order to be out of the subjects' view.

2) Actual Height (AH)

First of all, the subjects actually stepped over the bar from the same height as the PH that was measured before. They had two practice trials before measurement trials. If the first trial resulted in failure, that is, when the bar falls, the bar was lowered by 1 cm. Measurements were repeated thereafter until a height that subjects were able to step over was reached. On the other hand, if the result of the first trial was successful, the bar was raised by 1 cm. Measurements were repeated until a failure occurred. As a result of this procedure, maximum actual height that the subjects could step over was regarded as actual height (AH).

3) Leg Length (LL)

Measures of leg length were obtained for each subject so that PH and AH could be divided by leg length (LL) and became comparable values among individuals. LL was the sum of the upper leg length from trochanter major to lateral epicondyle of femur, and lower leg length from lateral epicondyle of femur to lateral malleolar of fibula. Standing height of all subjects was also measured.

Statistical Methods

Statistical analyses were performed with values of PH and AH divided by LL. The analysis was performed using statview 5.0. p values < 0.05 were considered statistically significant.

One-factorial ANOVA with Dunnett's multiple comparison post hoc test was used to determine differences of AH /LL, and PH /LL for each distance.

Results

Figure 1 displays the average values (±SD) of PH /LL at four distances and the AH /LL. The average of PH /LL gradually decreased with increasing distance, 1.029 (SD = 0.054) for 1 m, 0.986 (SD = 0.045) for 2 m, 0.940 (SD = 0.038) for 4 m and 0.901 (SD = 0.042) for 8 m. The ANOVA analysis showed statistical significance ($F_{4,45}$ = 6.426, p = 0.011) and the post hoc analysis revealed a significant difference between AH /LL and PH /LL at 4 m and 8 m.

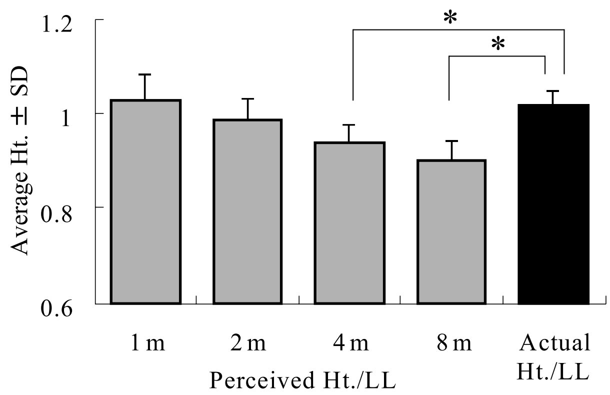

Fig. 1. Histograms showing Perceived Ht./Leg Length (LL) at four distances and Actual Ht./Leg Length (LL).
* Significant differences (p< 0.05).

Discussion

It was found from the result of the first experiment that the perception of affordances for the stepping-over task descended as the viewer distance became further. The result of the first experiment corresponded to the findings of the previous study using sitting down and climbing tasks[7]. In both present and previous studies, subjects tended to underestimate their perceived ability at further distances. The precision of estimation may become less important at distances that require considerable locomotion before the stepping-over action can begin. On the other hand, the precision of information may be important at relatively short distances.

However, the current results showed that the standard deviation of PH at short distances was wider, while, the standard deviation of PH at the 4-meter-distance was the smallest of all distances. Thinking of the following measurement, the results suggests that the perception of affordances can be more precisely obtained at this distance. One of the causes may be useful field of view. The angle of useful field of view is said to be approximately 20°[14]. At short distances useful field of view may be narrower than the height which subjects judged. In particular, in judging heights an eye-height scale is used[15]. In other words, the angle between eye-height line and the surface on which the judged obstruction is located is referred to as the judged height of it. Therefore, if the viewing distance becomes narrow, the angle between eye-height and the surface will be too wide to judge the obstruction. That is why the judgment at short distances becomes dispersed. For this reason, a 4-meter-distance was selected for the second experiment.

Experiment 2

Perceived Height and Actual Height of Aging Adults (60s, 70s and 80s) and Young Adults (20s)

Methods

Subjects

Subjects were young adults in their 20s and aging adults in their 60s, 70s and 80s. The subjects for young adults were students in Hiroshima University or Graduate School of Hiroshima University. None of them participated in the first experiment. The subjects for aging adults lived in a community of S town in H Prefecture. Selection criteria used required that participants did not have dementia and did not use a cane in daily living. Subjects who didn't have enough good eyesight and cognitive ability to make the measurements were also excluded.

The number of subjects was fifteen in their 20s (7 male, 8 female), eighteen in their 60s (5 male, 13 female), twenty-six in their 70s (8 male, 18 female), and fifteen in their 80s (6 male, 9 female). Mean ages were 23.3 (SD = 2.2) for the 20s, 63.4 (SD = 3.0) for the 60s, 73.8 (SD = 2.5) for the 70s and 83.3 (SD = 2.8) for the 80s. An examiner explained to all subjects the measurements and privacy policy, and they signed consent forms. Approval for this study was obtained from institutional (Graduate School of Health Sciences, Hiroshima University) review board.

Procedures

Measurements were taken for PH, AH and LL. The same equipment as the first experiment was used. The experimental procedure was also similar to that for PH, AH and LL of Experiment 1. For aging adults, grip strength, functional reach, and maximum walking time were assessed to examine their physical ability.

PH was obtained for only the 4 meter distance between subjects and the bar. The measurement interval was changed from 1 cm in Experiment 1 to 5 cm in Experiment 2 because aging adults can suffer from fatigue from a long measurement time. PH was measured by 5 cm intervals between 50 cm and 100 cm (11 heights) for young adults, and between 20 cm and 90 cm (15 heights) for aging adults. After the measurement of PH, AH was measured by 5 cm intervals from the same height as the previously measured PH. The measurement of AH was performed using the same procedure as in the first experiment.

Grip strength was measured in the dominant hand using a dynamometer while the subject was standing with elbow fully extended. The functional reach was measured as the maximal reach a participant could achieve while maintaining a fixed-based standing posture. Maximum walking time was obtained by timing how long it took for participants to walk as fast as possible for 10 meters. For all of the measurements of physical ability, the average of two trails was used as the score.

Statistical Methods

Statistical analyses were performed with values of PH and AH divided by LL. The statistical significance

Table 1. Characteristics of subjects

		Young adults	Aging adults		
		20s	60s	70s	80s
Perceived Ht. (cm)	Average	67.7	64.4	60.8	57.3
	SD	3.8	7.6	11.4	16.0
Actual Ht. (cm)	Average	74.3	65.0	59.6	56.3
	SD	5.6	6.2	6.9	12.6
Leg Length (cm)	Average	74.8	71.1	69.3	68.3
	SD	3.8	4.4	3.3	5.0
Participants' Ht. (cm)	Average	165.2	154.6	152.8	150.7
	SD	1.9	1.6	1.4	2.9
Perceived Ht./ LL	Average	0.903	0.907	0.873	0.832
	SD	0.018	0.019	0.028	0.050
Actual Ht./ LL	Average	0.993	0.915	0.859	0.818
	SD	0.010	0.014	0.016	0.035
Grip Strength (kg)	Average		26.8	24.9	23.9
	SD		8.2	7.9	8.5
Functional Reach (cm)	Average		35.8	30.7	25.6
	SD		9.4	7.4	8.2
Maximum Walking Time (sec)	Average		5.1	6.6	7.7
	SD		0.8	1.8	2.1

LL: Leg Length
* Significant differences (p< 0.05)

of differences between PH /LL and AH /LL intra-generationally was assessed with paired t-test. One-factorial analysis of variance (ANOVA) was used to determine whether differences of PH /LL and AH /LL inter-generationnally were statistically significant. In the case of a significant ANOVA, Scheffe post-hoc test was used to make multiple pairwise comparisons. Physical ability were also compared among the three aging groups using ANOVA with Scheffe post-hoc test. All analysis was performed using statview 5.0. p values < 0.05 were considered statistically significant.

Results

The average values and standard deviation of PH, AH, LL and standing height of each generation are shown in Table 1. The average of both PH and AH showed a tendency to decrease with the generation being older. PH and AH were divided by LL for each subject, and the average values and standard deviation are also shown in Table 1.

Physical ability is also displayed in Table 1. All of the items of physical ability were likely to decline with aging. The results of functional reach ($F_{2,56}$= 5.652, p= 0.0058) and maximum walking time($F_{2,56}$= 10.253, p= 0.0002) of younger aging adults were significantly better than those of older aging adults.

Figure 2 displays the average value (±SD) of PH/LL and AH /LL for each age group. We performed paired t-test to determine differences in PH /LL and AH /LL intra-generationally. The results revealed that PH /LL was significantly lower than AH for those in their 20s (t= 4.782, p=0.0003). On the other hand, there were no significant differences between PH and AH, for the aging adults in their 60s (t= 0.412, p= 0.6853), 70s (t= 0.578 p= 0.5682) or 80s (t= 0.420, p= 0.6810).

PH /LL inter-generationally showed no significant difference ($F_{3,70}$= 1.1, p= 0.36). However, compared with the average values of PH for those in their 20s and 60s, the average values for those in their 70s and 80s were slightly lower, and the standard deviation tended to widen. On the other hand, we observed a significant difference in AH inter-generationally ($F_{3,70}$= 12.83, p<0.0001). As a result of the post-hoc test, there were significant differences between those in their 20s and 70s (p=0.0001), 20s and 80s (p<0.0001), and 60s and 80s (p=0.0174), which showed that the older generations

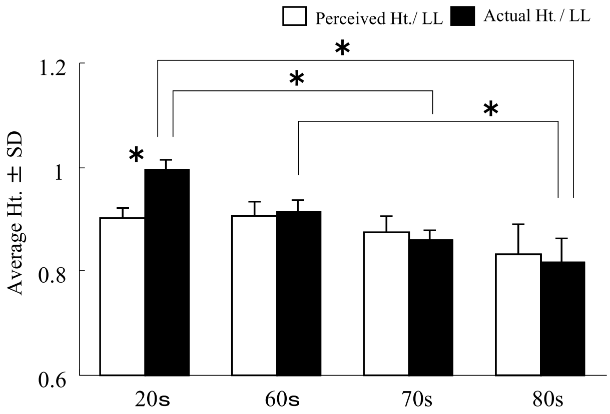

Fig. 2. Histograms showing four age groups, the average (± SD) of Perceived Ht./ Leg Length (LL) and Actual Ht./ Leg Length(LL).
* Significant differences ($p < 0.05$).

Table 2. AP value (Actual Ht. - Perceived Ht.) for each generation

AP value	Young adults	Aging adults		
(cm)	20s	60s	70s	80s
-20			1	
-15			1	1
-10			3	2
-5		6	6	4
0	4	6	8	4
5	5	3	4	2
10	6	3	1	
15			1	2
20			1	
total	15	18	26	15

Negative value shows underestimation and positive value shows overestimation.

were lower in all cases.

In order to examine the difference between PH and AH, the values of PH subtracted from AH (AP value) were calculated; the results were added up for each age group separately, and are shown in Table 2.

In their 20s, none who had a negative AP value existed. On the other hand, from those in their 60s to their 80s, there were many participants who had negative AP values; PH was higher than AH. The rates tended to increase as age increased: for those in their 60s, the ratio was 33.3%, 70s was 42.4%, and 80s was 46.7%. On the contrary, the ratios of subjects who had a positive AP value decreased. The ratio for those in their 20s was 73.3%, 60s was 33.3%, 70s was 26.9%, and 80s was 26.7%.

Discussion

In this study, we explored the features of perceived and actual action in young adults and aging adults that included people older than 80 years. We found that for the stepping-over task, which was easily hampered by aging, the perception of affordances did not show a generational difference, while the actual motor performance did. In particular, aging adults older than 80 years showed this tendency more clearly.

Motor performance

The age-related decrease in the height that they could step over was initially attributed to biomechanical factors. Aging affected the motor ability for the stepping-over task which required a high degree of motor skill, such as balance, muscle strength and joint flexibility, which are also known to decline with age. The results of this study also showed declination of physical ability with aging. Some studies have shown that muscle strength is connected with the stepping-over task for aging adults[16,17]. These studies have also described that a higher stepping task is more strongly correlated with lower body muscle strength, and demands more muscle activation. Body muscle, especially lower body muscle which is related to the stepping-over task, is easily affected by aging[18]. Moreover, unlike young adults, aging adults use different muscle co-contraction in order to balance themselves during upright standing because of a threat to the individual's ability to stay stable[19]. In addition, Konczack et al.[5] found correlation between hip flexibility and maximum height to be able to climb without their hands for aging adults. Stepping-over task requires individuals to raise up their legs the same as climbing steps does. Decreased muscle strength, balance, and joint flexibility with aging may reduce the height that aging adults can step over. Moreover, aging adults older than 80 years, compared to younger people, have more deterioration in this task.

Motor Perception

The most salient finding in this study was that the perception of affordances was less influenced by aging than actual actions. Surprisingly, even the group in their 80s didn't show a significant difference with the other age groups. These findings point out that the estimation of movement is stagnant, notwithstanding actual motor performance decline with aging. Perception of affordances ability progressively declines with age.

Motor perception is based on previous experience. The barrier crossing ability of infants is also most influenced by walking experience[2]. Aging adults may have less opportunity to experience walking or stepping over high obstructions. Therefore, they may not revise their motor perception in compliance with their motor performance.

Intra-generational comparison of motor perception with motor performance

Another important finding is that for all of the aging groups, there was no significant difference between estimated motor perception and actual motor performance. Conversely, actual performance of the young group was significantly higher than motor perception. We hypothesized that young adults would show correspondence between motor perception and actual motor performance, and on the contrary, aging adults, especially the group older than 80 years would show a gap. Other past studies which used a comparison of perceived to actual maximum motion indicated close coincidence of motor perception and actual motor performance[4-7]. This conflict between the present study and previous studies may be caused by the character of the measurement task.

Some studies of gait when stepping over obstacles demonstrated that the motion of the lower limbs resulted in a much larger clearance between the foot and obstacle than that found between the foot and ground during level walking[20]. This research may indicate that people need a safety margin to step over an obstacle. In the results of the present study, there were no young people whose PH was higher than the AH. Meanwhile, the number of negative AP values in the old group tended to increase with aging: 33.3% in their 60s, 42.4% in their 70s, and 46.7% in their 80s. Consequently, most young adults may have a safety margin, and some aging adults may not. This protective gait strategy may be peculiar to the motion of stepping over obstacles which are more dangerous.

We found that perceived height varied with the viewing distance in the first experiment. The perceived height became higher with farther distance between the bar and the participant. Moreover, the 4-meter-distance for the second experiment seemed to be an appropriate method because perceived heights at shorter distances were dispersed in the first experiment. Mark[7] reported that the perceived maximum height of climbing and sitting declined with viewing distance. This result is similar to that of the present study. People use levels of eye height to judge the height of objects[21]. The farther the distance between an object and a viewer is, the lower the level of eye height is[7]. Hence, young adults may have estimated that the actual performance was significantly higher than the perceived height at 4 m and 8 m viewing distances in the first experiment.

AP values showed that the relationship between PH and AH for the aging group differed more than that for the young group. This result indicated the difference between aging adults and young adults regarding motor performance and motor perception. If young people have excellent congruence between motor performance and motor perception, the congruence of aging adults may be disturbed. Owing to more decline in motor performance with aging, aging adults older than 80 years may have stronger confusion compared to younger ones.

Conclusion

As a conclusion, we propose that the gap between motor performance and motor cognition causes some risks in aged life such as falling. For proper movement of aging adults, cognitive feedback of movement may be important. In this study, we inductively speculated about the relationship between motor perception and motor performance from only the one task of stepping over a bar. Therefore, further studies examining other demanding tasks for aging adults may be necessary for a more complete understanding.

References

1. Gibson, E. J.: Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. Annu. Rev. Psychol., 39: 1-41, 1988
2. Kingsnorth, S. and Schmuckler, M. A.: Walking skill versus walking experience as a predictor of barrier crossing in toddlers. Infant Behav. Dev., 23: 331-350, 2000
3. Gibson, E. J. and Schmuckler, M. A.: Going somewhere: An ecological and experimental approach to development of mobility. Ecological Psychology, 1: 3-25, 1989
4. Warren, W. H.: Perceived affordances: Visual guidance of stair climbing. J. Exp. Psychol. Hum. Percept. Perform., 10: 683-703, 1984
5. Konczak, J., Meeuwsen, H. J. and Cress, M. E.: Changing affordances in stair climbing: the perception of maximum climbability in young and older adults. J. Exp. Psychol. Hum. Percep. Perform., 18: 691-697, 1992
6. Warren, W. H. and Whang, S.: Visual guidance of walking through apertures: Body-scaled information for affordanc-

es. J. Exp. Psychol. Hum. Percep. Perform., 13: 371-383, 1987

7. Mark, L. S.: Eyeheight-scaled information about affordances: a study of sitting and stair climbing. J. Exp. Psychol. Hum. Percep. Perform., 13: 361-370, 1987

8. Cerritelli, B., Maruff, P. and Wilson, P. et al.: The effect of an external load on the force and timing components of mentally represented actions. Behav. Brain Res., 108: 91-96, 2000

9 Decety, J., Jeannerod, M. and Prablanc, C.: The timing of mentally represented action. Behav. Brain Res., 34: 34-42, 1989

10. Sirigu, A., Duhamel, J. and Cohen, L. et al.: The mental representation of hand movements after parietal cortex damage. Science, 273: 1564-1568, 1996

11. Skoura, A., Papaxnathis, C. and Vinter, A. et al.: Mentally represented motor actions in normal aging I: Age effects on the temporal features of overt. Behav. Brain Res., 165: 229-239, 2005

12. Tokuda, T., Kodama, K. and Saijo, T.: Experimental study for shifting movements in relation to environmental adaptability in old age- Movements to stand or sit, ascend or descend, and step over in elderly women. The Japanese Journal of Ergonomics, 31: 9-20, 1995

13. Birgitta, L. L., Gunner, G. and Sten, L.: Functional studies in 79-years-olds.: Performance in Hygiene Activities. Scand J. Rehab., 15: 109-115, 1983

14. Yamanaka, K., Nakayasu, H. and Miyoshi, T. et al.: A Study of Evaluating Useful Field of View at Visual Recognition Task. Japan Society of Mechanical Engineers, 72: 244-252, 2006

15. Wrage, M.: Using eye height in different postures to scale the heights of objects. J. Exp. Psychol. Hum. Percep. Perform., 25: 518-530, 1999

16. Lamoureux, E. L., Sparrow, W. A. and Murphy, A.: The relationship between lower body strength and obstructed gait in community-dwelling older adults. J. Am. Geriatr. Soc., 50: 468-473, 2002

17. Hahn, M. E., Lee, H. J. and Chou, L. S.: Increased muscular challenge in older adults during obstructed gait. Gait & Posture, 22: 356-361, 2005

18. Candow, D. G. and Chilideck, P. D.: Differences in size, strength, and power and lower muscle groups in young and older men. J. Gerontol. A Biol. Sci. Med Sci., 60: 148-156, 2005

19. Bunjuya, N., Itshak, M. and Kaplanski, J.: Aging-induced shifts from a reliance on sensory input to muscle co-contraction during balanced standing. J. Gerontol. A Biol. Sci. Med. Sci., 59: 166-171, 2004

20. Chou, L. S., Draganich, L. F. and Song, S. M.: Minimum energy trajectories of the swing ankle when stepping over obstacles of different height. J. Biomech., 30: 115-120, 1997

21. Patla, A. E. and Rietdyk, S. :Visual control of limb trajectory over obstacles during locomotion: effect of obstacle height and width. Gait & Posture, 1: 45-60, 1993