Age-Related Differences in Gross Motor Skills

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ABSTRACT
Body-based interfaces have recently attracted much attention. In such interfaces, gross motor skills are critical in providing a safe and pleasant experience. However, little is known about gross motor performance, particularly on the age-related differences between the elderly and young adults. This study compares simple gross motor skills of the elderly with those of younger adults when performing arm and leg movements in different directions and different time intervals. By measuring participants' body movements during the task, we identified movement ranges, awkward movements, and the appropriate time interval between consecutive movements. We conclude by providing relevant HCI design implications.

Author Keywords
Gross motor skills; elderly; older adults; input; design implications.

ACM Classification Keywords
H.5.m [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces- Miscellaneous.

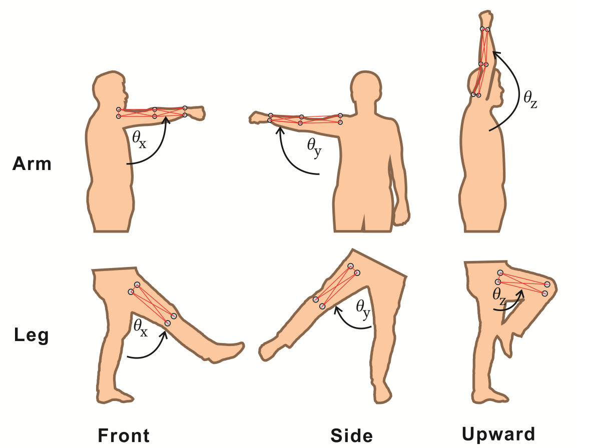

Figure 1. Three basic movements: front, side, upward for arm and leg.

INTRODUCTION
Gross motor skills play a crucial role in Human-Computer Interaction (HCI). Gross motor skills such as performing large movements with the arm, leg, or the whole body are involved in numerous body-based user interfaces including mid-air [9] and large display interfaces [11], motion-based game interfaces [8], body-centric interfaces [15], or any situation where gross motor skills are used for input. Thus measuring gross motor skills is one of the fundamental aspects of measuring human performance. On the other hand, it is well-known that aging comes with a decline in sensorimotor [1, 2] as well as cognitive and perceptual functioning [12]. The elderly typically perform tasks more slowly, less accurately with a lower range than they once did. Current body-based interfaces do not adequately consider the physical limitations of the elderly. For example, playing exergames that are not appropriately designed for the elderly can greatly increase the risk of injuries [5], and frustrate the elderly from the gameplay. Consequently, considering age-related differences in gross motor skills is an essential factor of HCI design for the elderly.

However, despite this apparent importance, little is known about the gross motor performance, especially in the comparison between the elderly and young adults. In other words, what are the notable differences between the elderly and young adults? What are some useful capabilities that HCI designers can exploit? What are some key considerations that designers should particularly pay attention to?

Although motor skills of the elderly have been explored by several HCI studies [4,17], the majority of the literature mainly focuses on fine motor skills of the elderly. For example, Findlater et al. [4] studied the performance of the elderly and young adults for different tasks using mouse and touchscreen. However, the aging process causes declines in not only fine motor skills but also gross motor skills [1]. Outside the HCI field, a number of studies have investigated the gross motor skills comparing the elderly and young adults. For example, age-related differences with ball-juggling task [10] and walking performance over a treadmill [18] have been explored. Nevertheless, these studies may not be directly applicable to HCI design. From these past works, it suggests a need for a more

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rigorous investigation on gross motor performance, in order to derive useful implications for HCI design.

We adopted an ergonomic approach, which did not include any use of user interfaces to investigate the fundamental capabilities of the participants. We analyzed the simple gross motor skills of the elderly and young adults. Specifically, we investigated the spatial and temporal characteristics of arm and leg movements in basic directions and various time intervals (see Figure 1). We quantified and analyzed the movement information of the elderly and young adults, to assess the weaknesses and strengths of the elderly in arm and leg movements.

Our study contributes by presenting useful design implications for HCI design through studying age-related differences in gross motor skills. We propose safe and pleasant interfaces for the elderly by avoiding awkward directions and improper time intervals of arm and leg movements.

RELATED WORK

Body-based Interfaces

Recently, researches on body-based interfaces have attracted much attention due its intuitiveness and ubiquity. For example, Nancel et al. [9] presented mid-air gestures for interaction with the wall-sized display. They presented pan-zoom navigation technique and showed significant improvement on performance. Shoemaker et al. [13] presented mid-air text input techniques in comparison to traditional text input modalities. Another useful interface which demands gross motor skills is large display interface. Several studies proposed new interaction methods to improve the interaction with large displays. For example, Shoemaker et al. [14] used perspective projection to facilitate users to reach further distant targets on large displays. Khan et al. [7] developed 'Frisbee', a new interaction technique for manipulating the areas which are difficult to access. Another technique which uses human gross motor skills is body-centric interfaces, e.g., opening the menu by touching your hips [15]. Motion-based video games are also gaining popularity given that it can provide health benefits to the users [16]. Researchers have proposed design guidelines for senior-centered game design. For example, Ijsselsteijn et al. [6] demonstrated age-related changes in sensory, cognitive and motor properties and provided design instructions for the elderly game design. Gerling et al. [5] presented general guidelines for designing motion-based games for the elderly in nursing homes.

These studies, in general, demonstrated the popularity of body-based interfaces. However, few studies have investigated the gross motor performance, especially the age-related differences of the elderly in comparison with the younger adults. We seek to provide HCI design implications regarding elderly's gross motor performance.

Aging and HCI

Motor skills of the elderly have been explored by several HCI studies [4, 17]. The majority of the literature mainly focuses on the fine motor skills of the elderly. For example, Findlater et al. [4] studied the performance of the elderly and young adults in different tasks using mouse and touchscreen. St*öβ*el et al. [17] studied age-related differences in gesture inputs for touch surfaces. However, the aging process causes declines in both fine and gross motor skills [1]. Thus studying gross motor skills of the elderly is necessary and timely given the fast-growing field of body-based interfaces. Without understanding gross motor performance, it is difficult to design useful and pleasant user interfaces.

Gross Motor Skills

Gross motor skills involve large muscle movements such as walking or raising the arm. There are a lot of studies in Kinesiology[1] on studying age-related differences in motor skills [3]. In addition, there are a number of studies focusing on training the gross motor skills of the elderly. For example, Perrot and Bertsch [10] trained the elderly and younger adults with ball juggling task. Hedel and Dietz [18] trained users' walking performance through a treadmill and stepping over obstacles. Our work also focuses on gross motor performance but instead of training, we investigate users' gross motor performance in types of motions that are prevalent in body-based interfaces. We seek to understand age-related differences in gross motor skills to derive some useful design implications for body-based interfaces.

To sum up, for designing suitable and pleasant body-based interfaces for the elderly, we have to consider their limited physical and cognitive capabilities. Therefore it is crucial to investigate users' gross motor performance.

EXPERIMENT

The study focuses on analyzing range of motion (ROM), movement time (MT), recovery time (ET) [2] and total time (TT) of arm and leg movements performing in three directions with three time intervals. Studying the differences in arm and leg input properties between the elderly and younger adults will provide design implications which can be utilized for designing body-based interfaces for the elderly.

Participants

Ten elderly aged $66-84$ ($M = 71.9$, $SD = 6.2$) and ten younger adults aged $21-22$ ($M = 21.7$, $SD = 0.45$) were recruited. All were male and right-handed, and none suffered from any visual, auditory, physical or mental impairments. Elderly and young participants reported doing exercise one to four hours per week. All young participants had used body-based interfaces (e.g. motion-based games) before, while only one elderly participant had prior experience. All participants were paid $10.

Apparatus

The experiment was conducted using a VICON Motion Capture System including a twelve Bonita B10 camera system (frame rate: 250 fps, resolution: 1 megapixels, lens operating range: up to 13 m, angle of view wide (4mm): 70.29° × 70.29°, angle of view narrow (12mm): 26.41° × 26.41°). Ten markers attached to the shoulder, elbow, wrist, thigh and knee were

[1] Kinesiology is a scientific study of the mechanics of body movements.

[2] We used ET instead RT to avoid confusion between recovery time and reaction time

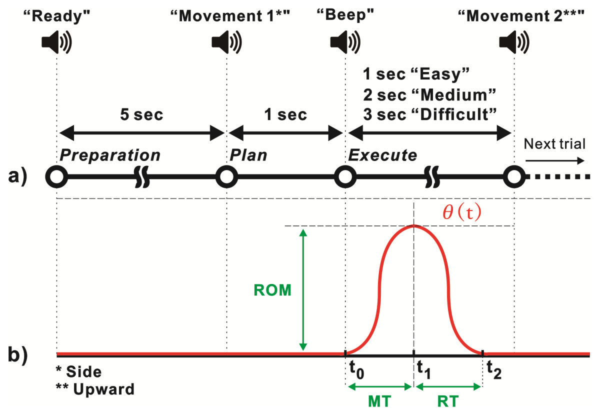

Figure 2. (a) Trial design, (b) Motion signal.

prepared where these markers were used to represent an arm-like and leg-like segments. Nexus 2.1.1 software was used to record and extract the location data. MATLAB R2015a was used to analyze motion data. C# software was used to synchronize the auditory tasks with VICON. All programs ran on a 2 GHz Intel Xeon CPU PC with Windows 7. Participants were provided a 49 m^2 area to move their body parts comfortably.

Task and Procedure

Participants were first asked to sign a consent form and to fill out their demographic information including their health background, to ensure that participating in our experiment is safe. Then participants were informed about the procedure and the goal of the study. A total of ten markers (4mm wide) were attached to each participant's shoulder, elbow, wrist, thigh and knee (See Figure 1). VICON cameras were calibrated using a T-shaped wand before starting the experiment. Afterward, participants were instructed to stand in the center of twelve VICON cameras and move their arms or legs in directions as instructed.

Participants were asked to do abduction (moving body-input away from body's midline) and adduction (moving body-input toward the body's midline) movements for each body-input. For the arm movement, participants were instructed to "*move the dominant arm to each direction as comfortable, fast and accurate as possible they can*". For precise instruction about the arm position they were asked to "*move arm perpendicular to the torso in the front and side movements, and move arm parallel to the torso in the upward movement*". However, for leg movement they were instructed to "*move dominant leg to each direction as comfortable, fast and much as possible they can*". Through biomechanical limitations in the physical structure of human leg, participants were not instructed to reach to a specific position. Finally, they were instructed to return arms or legs to the body's midline, after performing each movement.

Figure 2 shows the detailed procedure. Auditory instruction (*'Ready!'*) was first issued to get the participants mentally and physically prepared. After five seconds of waiting, during each trial an auditory instruction regarding the direction (*'Front!'* or *'Side!'* or *'Upward!'*) was played as a preparation signal for the execution of the task. After one more second, a *'beep'* sound was played and participants then had to move their arms or legs. Movement type was designed as a movement delayed by one second. Participants were first given a key (the name of the direction) so that they were confident about which action they have to perform; this ensured that we were actually measuring the simple gross motor skills of participants and not the differences between mental preparations time or reaction delays related to the subjects' decision-making ability.

The directional instruction and the *'Beep'* sound were then played repeatedly until participants performed all movements in each specified block. The trials were conducted in three blocks which each contained nine movements in randomized order of time intervals and directions.

We used a mixed factor design where participants were instructed to perform movements in a specified direction and time interval across a set of continuous stimuli. The *'Group'* was between-subjects, comparing elderly and younger adults. The *'Body-input'* was within-subject, asking participants to move their body using two parts: arm and leg. The *'Direction'* was within-subject, asking users to perform movements in three directions: front, side, upward. The *'Time interval'* was within-subject, providing the task with three time intervals between two stimuli: long (3 sec), medium (2 sec), and short (1 sec). In summary, the experiment consisted of:

10 participants ×
2 age groups ×
2 body-inputs ×
3 directions ×
3 difficulties ×
3 blocks ×
= 1080 trials.

The arm experiment was finished before the leg experiment. At the end of the experiment, a questionnaire was used to gather subjective ratings of the participants. The participants were asked to rate the comfortability of *Direction* and *Time interval* on a 7-point Likert scale questionnaire. The whole experiment for arm and leg took one hour and it was video-recorded for later analyses.

Metrics

Arm and leg movements were measured by recording XYZ coordinates for the ten markers. To fill gaps originated from hidden markers that rarely happened during motion capture experiment, data were preprocessed using Nexus software. To estimate the quality of performed movements, the angles between the torso and displacement of the arm, and also between the torso and displacement of the leg were calculated.

For instance, to find angle of the front movement of arm, XZ coordinates of shoulder and wrist markers were used to calculate the length of ST (shoulder-torso) and TW (torso-wrist) lines as (1) and (2) (see Figure 3 [Arm-b]).

$$\bar{ST}_{arm}(t) = \sqrt{(z_T - z_S)^2 + (x_T - x_S)^2} \quad (1)$$

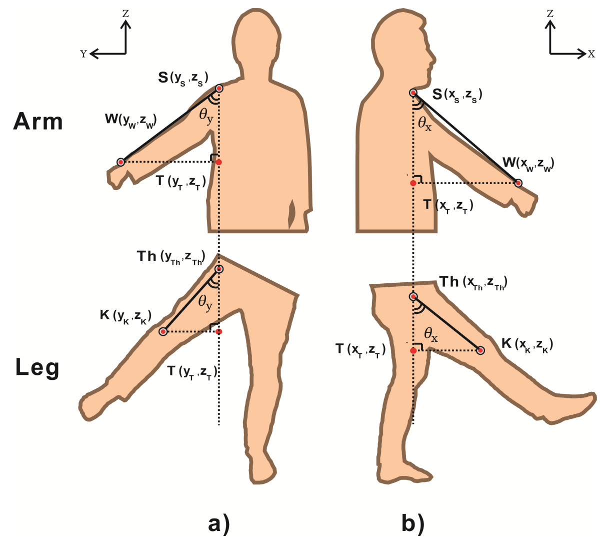

Figure 3. Angle in (a) YZ plane (the side direction) and (b) XZ plane (the front and upward directions).

$$T\bar{W}_{arm}(t) = \sqrt{(z_W - z_T)^2 + (x_W - x_T)^2} \qquad (2)$$

Angle time course of front arm movement was calculated as (3).

$$\theta_{x,Arm}(t) = \arctan\left(\frac{T\bar{W}_{Arm}(t)}{S\bar{T}_{Arm}(t)}\right) \qquad (3)$$

Next, four dependent variables including ROM, MT, ET and TT were analyzed using an angle time course (see Figure 2). ROM is a spatial range of the body-inputs which is equal to (4).

$$ROM_{x,Arm} = \theta_{x,Arm}(t_1) \qquad (4)$$

MT is a temporal delay during abduction movement that is measured from the start point (body's midline) to the end point. MT was calculated as (5).

$$MT_{x,Arm} = t_1 - t_0 \qquad (5)$$

ET is a delay time of adduction that participant need to return the body-input to the body's midline after doing the movement to prepare for the next movement. ET was calculated as (6).

$$ET_{x,Arm} = t_2 - t_1 \qquad (6)$$

Finally, we also calculated total time (TT) as (7). We only used TT to find differences between arm and leg.

$$TT_{x,Arm} = MT_{x,Arm} + ET_{x,Arm} \qquad (7)$$

RESULTS

We focus on the main and interaction effects in *Group*, *Direction*, *Time interval* and *Body-input*. The data failed to conform to parametric evaluation through the Kolmogorov-Smirnov and Shapiro-Wilk tests. Thus, we analyzed our data with Friedman test. Post hoc tests were done using Wilcoxon Signed-Rank tests.

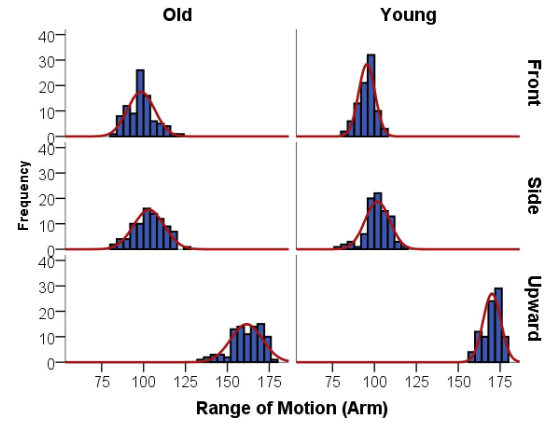

Figure 4. Distributions for ROM (Arm).

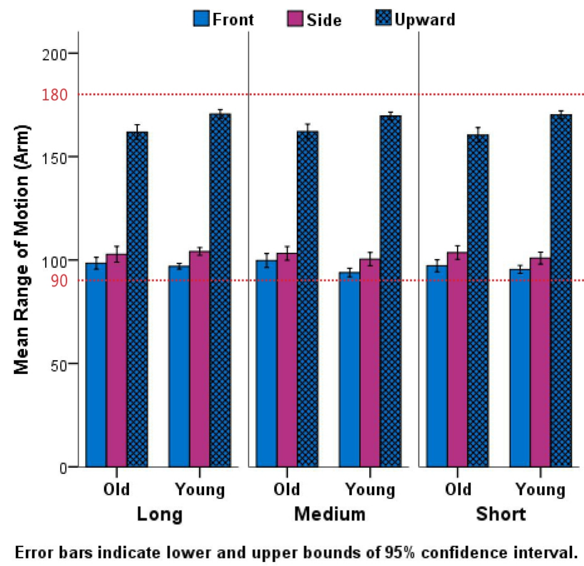

Figure 5. Mean for ROM (Arm). Red lines indicate expected ROM. Participants were instructed to reach 90º for the front and side movements, and 180º for the upward movement.

Arm

Three dependent variables were analyzed to study spatial and temporal characteristic of simple gross motor skills for arm movement.

Range of Motion (ROM)

We seek to understand awkward and comfortable arm movements by studying ROM. Figures 4 and 5 show the distributions and mean of ROM, respectively. Figure 6 also shows the heat map representation of arm ROM in three directions.

We found a main effect in *Direction* ($\chi^2(2) = 290.663$, $p < 0.001$). Post hoc pairwise comparisons revealed a significant difference between the front ($M = 97.0$º, $SD = 6.9$) and side ($M = 102.4$º, $SD = 8.3$) movements ($Z = -8.595$, $p < 0.001$), between the front and upward ($M = 165.6$º, $SD = 8.5$) move-

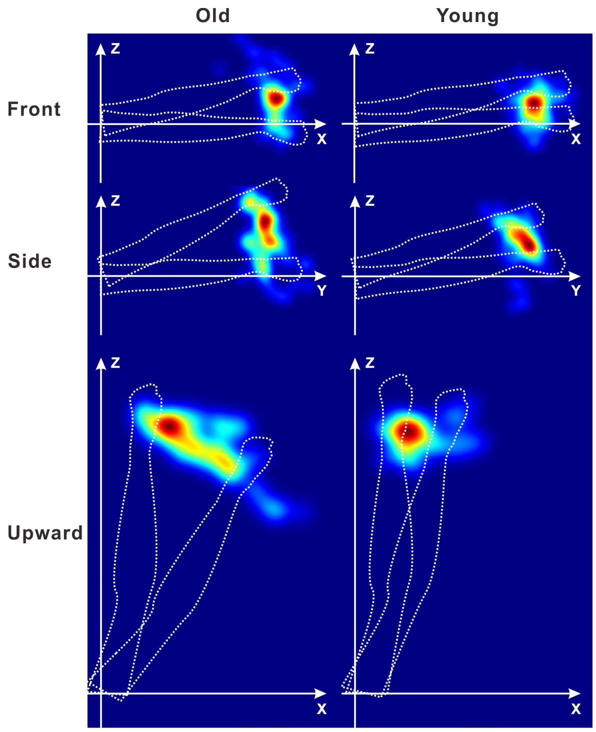

Figure 6. Heat map for arm's ROM in different directions and groups. Younger adults were more accurate, while the elderly suffered from less control. The upward movement was the most difficult movement for the elderly.

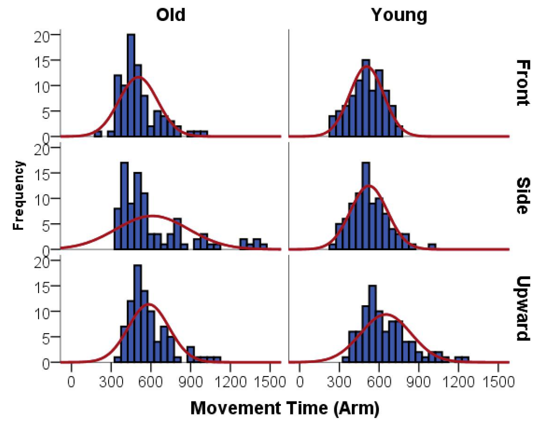

Figure 7. Distributions for MT (Arm).

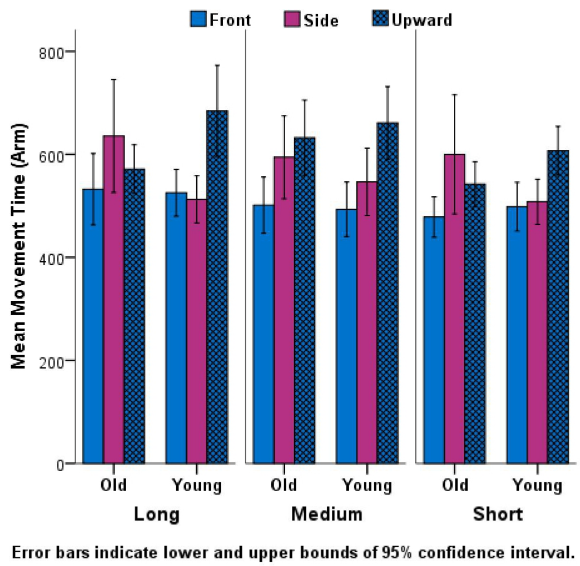

Figure 8. Mean MT (Arm).

ments ($Z = -11.473$, $p < 0.001$), and also between the side and upward ($Z = -11.505$, $p < 0.001$) movements. Expected arm positions are 90°, 90° and 180° for the front, side and upward movements, respectively. The result suggested that participants have higher control on the their arm while performed the front ($\theta_{error} = +7.0°$) rather than side ($\theta_{error} = +12.4°$) movements (see Figure 6), and they often overshooted the expected positions. Conversely, they never reached to the expected position for the upward movement ($\theta_{error} = -14.4°$).

To study interaction effect in *Group* × *Direction*, post hoc tests between different *Group* and *Direction* were performed. Naturally, young adults performed with greater accuracy than the elderly. While young adults ($M = 95.4°$, $SD = 4.8$) have higher control on their arm in the front movement ($Z = -2.810$, $p < 0.01$) than the elderly ($M = 98.4°$, $SD = 8.1$), the upward movement was an awkward direction ($Z = -6.094$, $p < 0.001$) for the elderly ($M = 161.4°$, $SD = 9.5$) rather than young adults ($M = 170.0°$, $SD = 5.2$).

Movement Time (MT)

To study appropriate time interval we analyzed MT. The distributions and mean of MT are shown in Figures 7 and 8, respectively.

We found a main effect in *Direction* ($\chi^2(2) = 76.144$, $p < 0.001$). Post hoc tests showed that there was a significant difference between the upward ($M = 605.7$ ms, $SD = 167$) and front ($M = 501$ ms, $SD = 136$) movements ($Z = -7.418$, $p < 0.001$), between the upward and side ($M = 547$ ms, $SD = 201$) movements ($Z = -5.336$, $p < 0.001$) and also between the side and front movements ($Z = -2.519$, $p < 0.05$). The results indicated that participants executed the front movement more quickly than the side movement. Also the side movement was finished more quickly than the upward movement. The results were expected, because movements with higher ROM have higher MT.

There was also a main effect in *Time interval* ($\chi^2(2) = 11.429$, $p < 0.01$). Post hoc comparisons revealed significant differences between the short ($M = 531$ ms, $SD = 171$) and long ($M = 569$ ms, $SD = 193$) time intervals ($Z = -3.609$, $p < 0.001$), likewise between the short and medium ($M = 564$ ms, $SD = 180$) time intervals ($Z = -2.709$, $p < 0.01$). But there was no difference between the long and medium time intervals. This is likely because the one second time interval was not enough for such movements, and participants pre-

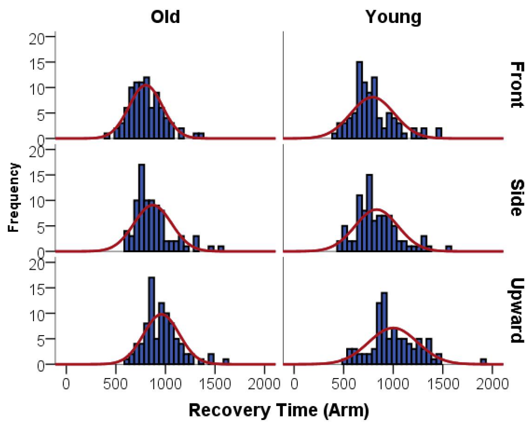

Figure 9. Distributions for ET (Arm).

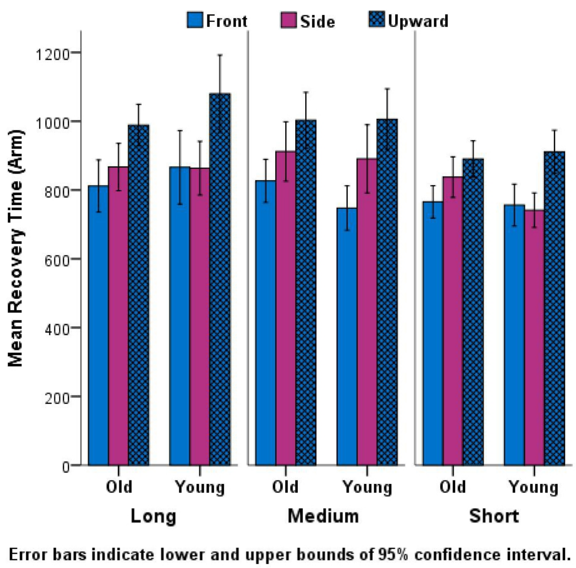

Figure 10. Mean ET (Arm).

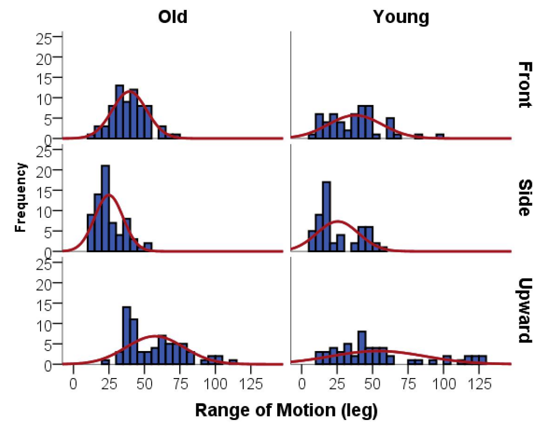

Figure 11. Distributions for ROM (Leg).

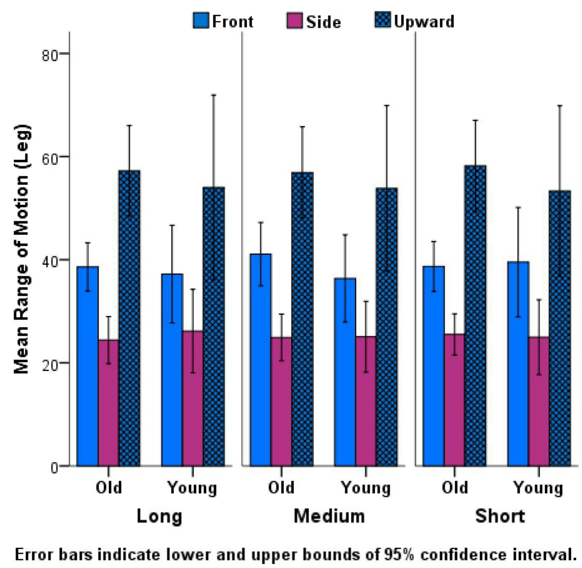

Figure 12. Mean for ROM (Leg).

ferred to quickly finish the movement to catch up with the next movement.

There was also an interaction effect in *Group* × *Direction*. Unlike the elderly, younger adults have higher MT while performing the upward ($M = 650$ ms, $SD = 189$) compared to the side ($M = 522$ ms, $SD = 139$) movements ($Z = -6.609$, $p < 0.001$). Consistent with earlier results, the findings were stemmed from the difference between ROM of the side and upward movements. Furthermore, the elderly have lower MT ($Z = -2.589$, $p < 0.01$) while performed the front movement ($M = 504$ ms, $SD = 145$) in comparison to the side movement ($M = 610$ ms, $SD = 273$), suggesting that the front movement is more easier to do than the side movement for the elderly.

Recovery Time (ET)

Users after executing the movement need to prepare for the next movement by returning their arm to the body's midline. So we analyzed ET for a better understanding of the appropriate time interval.

Figures 9 and 10 show the distributions and mean of ET. There was a main effect in *Direction* ($\chi^2(2) = 152.755$, $p < 0.001$). Post hoc tests revealed a significant difference between the upward ($M = 974$ ms, $SD = 212$) and front ($M = 788$ ms, $SD = 193$) movements ($Z = -10.101$, $p < 0.001$), between the upward and side ($M = 846$ ms, $SD = 198$) movements ($Z = -7.939$, $p < 0.001$), and between the front and side movements ($Z = -4.558$, $p < 0.001$). Our findings suggest that higher time interval should be provided for participants for performing the upward movement.

We found an interaction effect in *Group* × *Direction*. Elderly ($M = 959$ ms, $SD = 179$) have lower ET in the upward movement ($Z = -2.050$, $p < 0.05$) compared to the younger adults ($M = 998$ ms, $SD = 246$). The results suggest that between

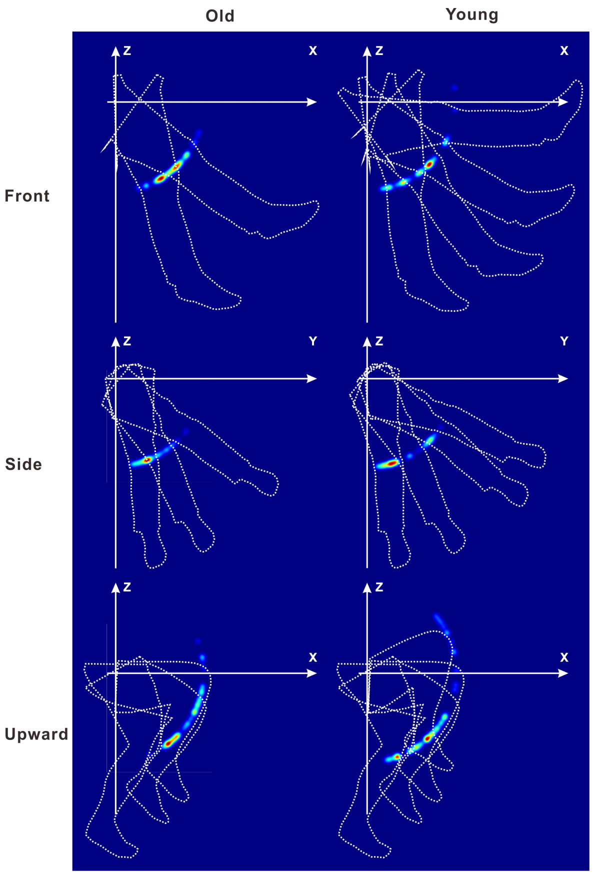

Figure 13. Heat map for leg's ROM in different directions and groups. Young adults have wider range. The side movement was a limited movement for both age groups.

Group differences is higher for the upward movement than other movements.

Finally, by analyzing interaction effect in *Group* × *Direction* we found for short time interval, younger adults ($M = 802$ ms, $SD = 172$) recover their arm faster ($Z = -2.150$, $p < 0.05$) than the elderly ($M = 831$ ms, $SD = 149$), indicating that short time interval definitely is not proper for the elderly.

Leg

Motor skills of the leg movement were analyzed, as well as arm movements.

Range of Motion (ROM)

We studied leg's ROM to understand awkward and comfortable leg movements. Figures 11 and 12 show the distributions and mean ROM for the leg. Figure 13 illustrates leg ROM using heat map.

There was a main effect in *Direction* ($\chi^2(2) = 153.187$, $p < 0.001$). Post hoc tests showed significant difference between the upward ($M = 55.7$º, $SD = 26.7$) and the side ($M = 25.1$º, $SD = 12.2$) movements ($Z = -9.194$, $p < 0.001$), between the upward and front ($M = 38.6$º, $SD = 15.4$) movements ($Z = -7.282$, $p < 0.001$), and between the front and side movements ($Z = -8.011$, $p < 0.001$). Our results indicated

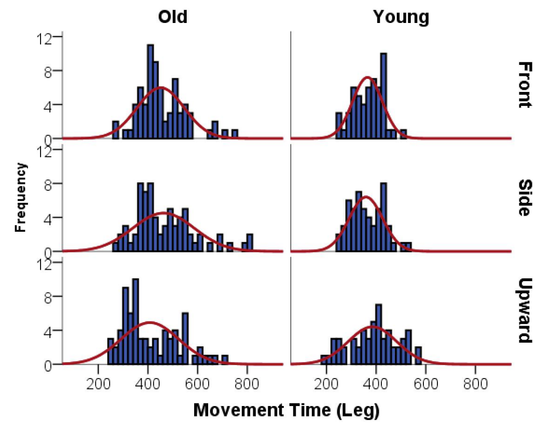

Figure 14. Distributions for MT (Leg).

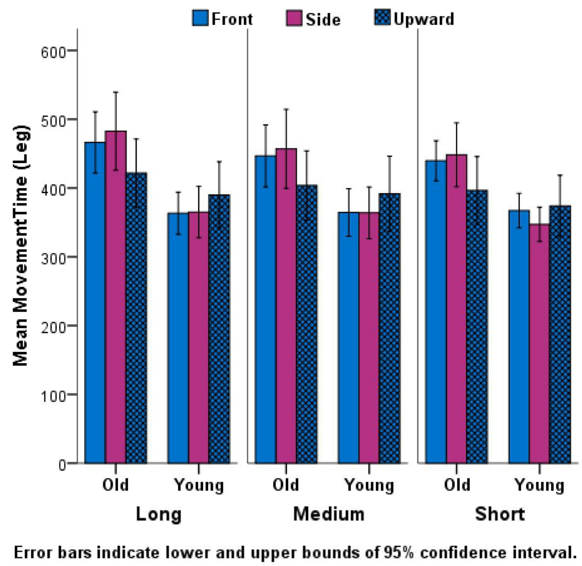

Figure 15. Mean MT (Leg).

that the side movement is the most limited leg movement for both age groups. In addition, our observations from leg experiment also elucidated that the elderly suffered from the balance problem after executing the side movement. This may caused by biomechanical structure of human body which extensibility of the leg muscles for side movement are more restricted.

On the other hand, our results showed wider ROM distribution for the upward movement in both age groups (See Figure 13), suggesting that the upward leg movement is highly affected by individuals' performance rather than *Group*.

Movement Time (MT)

MT was investigated to analyze the amount of time for executing each leg movement in different directions and time intervals. Figures 14 and 15 show the distributions and the mean MT. There was a main effect in *Group* ($Z = -5.871$ ms,

$p < 0.001$). As expected, the elderly ($M = 440$ ms, $SD = 113$) were overall slower than young adults ($M = 369$ ms, $SD = 77$).

There was also a main effect in *Direction* ($\chi^2(2) = 7.272$, $p < 0.05$). Post hoc tests showed differences between the upward ($M = 395$ ms, $SD = 107$) and side ($M = 416$ ms, $SD = 115$) movements ($Z = -2.030$ ms, $p < 0.05$), between the upward and front ($M = 410$ ms, $SD = 86$) movements ($Z = -2.472$ ms, $p < 0.05$), but not between the side and front movements. Interestingly, the upward movement for leg was faster than other movements.

Post hoc tests also showed an interaction effect in *Group* $\times$ *Direction*. There was significant differences between the upward ($M = 407$ ms, $SD = 115$) and side ($M = 462$ ms, $SD = 123$) movements ($Z = -4.222$ ms, $p < 0.001$), and between the upward and front ($M = 450$ ms, $SD = 94$) movements ($Z = -4.214$ ms, $p < 0.001$), but not between the front and side movements for the elderly. We also found that for performing the front movement, the elderly ($M = 450$ ms, $SD = 94$) have higher MT ($Z = -4.339$ ms, $p < 0.001$) than young adults ($M = 365$ ms, $SD = 59$). Also there was significant difference between the elderly ($M = 462$ ms, $SD = 123$) and young ($M = 358$ ms, $SD = 67$) for the side movement ($Z = -4.295$ ms, $p < 0.001$). But there was no significant difference between *Group* when the upward movement was performed. Although, elderly naturally were slower than young adults in leg movement, the elderly's performance was as good as younger adults when they performed the upward movement.

Recovery Time (ET)

ET was analyzed to assess time interval which participants need to recover their leg to the body's midline for the next movement. Figures 16 and 17 show the distributions and mean ET. There was a main effect in *Group* ($Z = -7.627$ ms, $p < 0.001$). Predictably, the elderly ($M = 659$ ms, $SD = 158$) required higher time to recover than young adults ($M = 523$ ms, $SD = 96$).

Arm vs. Leg Analysis

We examined differences in simple gross motor skills between arm and leg, to study the potential efficiency of each body-input for body-based interfaces. By analyzing TT between arm and leg we found a main effect in *Body-input* ($Z = -14.721$ ms, $p < 0.001$). The results showed that performing arm movement ($M = 1436$ ms, $SD = 341$) was more time consuming than leg movement ($M = 1006$ ms, $SD = 223$). Our findings also were confirmed by comparing MT and ET between arm and leg.

Subjective evaluation

At the end of the experiment, a questionnaire was used to gather subjective opinions of elderly participants. The elderly were asked to rate *Direction* regarding difficulty. 7-point Likert scale questionnaire was used (1 = *Not at all*, and 7 = *Extremely*). Moreover, they were asked to rate the most comfortable *Time interval*.

We did not find a main effect in *Direction*. The upward and side movements was ranked as the most difficult *Direction* for arm and leg, respectively. However, there was a main effect in

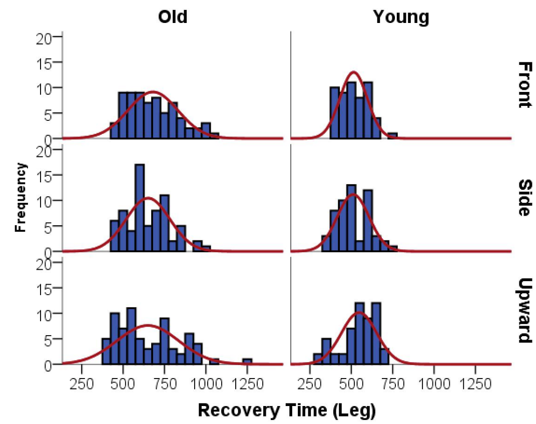

Figure 16. Distributions for ET (Leg).

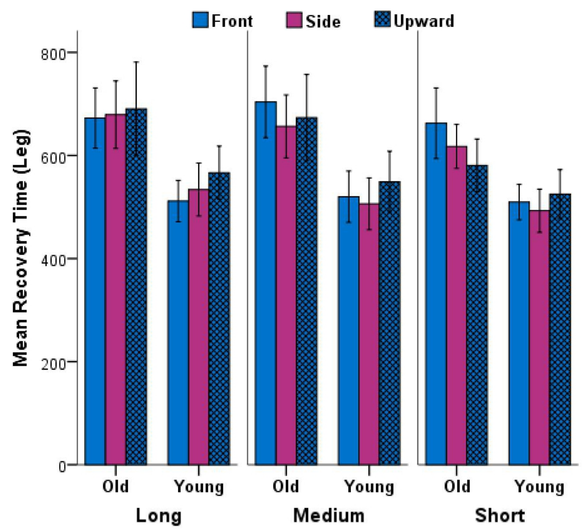

Figure 17. Mean ET (Leg).

Time interval ($\chi^2(2) = 14.600$, $p < 0.001$). Nine participants rated the medium time interval as the most comfortable *Time interval* for arm and leg.

DESIGN IMPLICATIONS

Based on our experimental results, we suggest design implications for body-based interfaces of the elderly considering arm and leg gross motor skills.

- *Avoid upward movement:* Any input that requires upward movement (e.g. touching a far away spot on a large display, performing a gesture of "Move hand up") should be avoided. Instead, it is recommended to leverage input that uses front and side arm movement. When upward movements are really needed, manipulating control display (CD) gain, shifting the display, or increasing the target size may be some viable solutions to provide more pleasant experience.

- *Avoid sustained movement:* Our study found that the elderly cannot efficiently perform the sustained movement. For example, a dwell-based selection technique, where users need to dwell hand on a target for a period of time to select it, should be avoided. One alternative solution is to use bimanual interaction (e.g. using arm and leg to compensate each other). Our study showed that the front and upward leg movements can be exploited. For example, to avoid dwell-based technique, one can use the hand for pointing while use leg for selecting a target.

- *Provide feedback to minimize overshooting and undershooting:* Our study confirmed that the elderly suffers from inaccuracy. They either overshot with their front and side movements, or undershot on their upward movement. Thus designers should provide appropriate feedback (e.g. visual or haptic feedback) to enhance the accuracy of the elderly's movements.

- *Avoid side leg movements:* Our analyses showed that the side leg movements were limited and prone to injury, and can lead to fall for the elderly. Thus, any interfaces that use leg as input (e.g. motion-based games) should avoid such side movements.

- *Put appropriate time interval between two consecutive stimuli:* In certain tasks such as motion-based games, or pointing to two or three consecutive targets (e.g. using the menu on large display interfaces), our experimental results recommended at least two seconds between two stimuli for providing effective interaction. The suitable time interval can reduce frustration for the elderly.

LIMITATIONS AND FUTURE WORK

To address generalizability of the findings we discuss several issues about limitations of our work. First, we did not observe reaction time. Our experiment was designed as a movement delayed by one second, to focus on differences in simple gross motor skills.

Second, our work recruited all male participants. Although this can be a threat to our generalizability, we speculate that there is no huge gap between male and female in terms of age-related differences. Also, our sample size was restricted due to between-group design. Nevertheless, gender differences using a larger sample size need to be further scrutinized.

Third, our work adopted an ergonomic approach, which did not include the use of any user interfaces. Instead, we asked participants to move to some body-referred target to understand their raw capabilities but such approach might be subjective. Thus one important future work is to apply the selection of external targets that leave no room for subjectivity and offer a more natural basis for accuracy measurements.

Fourth, our work did not specifically instruct the participants to stop their arm in top position. Instead, we asked participants to move to the top position and return to the original position in a natural way. Although we were able to observe their natural abilities, we were not able to perform more in-depth analysis of user endurance from ET.

CONCLUSION

Gross motor skills is a fundamental capabilities used in every body-based interfaces. Thus it is important to understand gross motor performance in order to develop safe and pleasant body-based user interfaces. Our work elucidated interesting movement differences between age groups, body-inputs, directions and time intervals. Our study proposed practical design implications for HCI designers for the elderly in such a way that avoid discomfort and injury due to awkward directions and improper time intervals of arm and leg movement.

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