

Title of Thesis

**Study on Influence of Visual Information on
Tactile and Kinesthetic Perception**

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Abstract

Many evidences of previous researches have shown that human nervous system integrates signals from visual and tactile modalities to maximize the information available for perception and action. In general, the tactile and kinesthetic perception about the environment is usually acquired by visual modality at the same time. The influence of visual information on tactile and kinesthetic perception is of growing concern. However, the influence of restricted visual conditions on tactile motion and visual-tactile intermodal interactions are not completely clear, especially the difficulties of the influence of aging on pointing movement under restricted visual condition and speed matching between visual and tactile motion. Aiming at above mentioned difficulties, two behavior experiments were conducted and an engineering application of pointing movement was presented.

Firstly, the visual and tactile speed discrimination under unimodal and crossmodal speed reproduction tasks were performed to investigate the speed matching interaction between visual and tactile motion. The present study showed that both visual discrimination speed and tactile visual discrimination are underestimated relative to the standard speed at relatively high speeds during unimodal tasks. The present study suggests that speed matching is processed similarly in both the visual and tactile sensory systems. Moreover, the present study demonstrated reciprocal interactions between the processing of visual speed matching and tactile speed matching. Visual speed stimuli positively affected tactile speed matching, whereas tactile speed stimuli disrupted visual speed matching at relatively high speeds. The reciprocal interactions between visual and tactile speed matching modalities directly support the view that at some point in the motion processing stream, these two modalities have partially overlapping substrates.

Secondly, the present study focuses on the influence of aging on pointing movements and test whether Fitts' law applied to the elderly adults under restricted visual feedback of hand's movement and target location. This study suggested that

Fitts' law applied for pointing movements of the elderly adults under different visual restriction conditions. Moreover, significant main effect of aging on movement times has been found in all four tasks. However, no significant main effects of age on mean accuracy rate under condition of restricted visual feedback were found. The present study suggested that the elderly subjects made a very similar use of the available sensory information as young subjects under restricted visual feedback conditions. In addition, during pointing movement, information about the hand's movement was more useful than information about the target location for young and elderly subjects.

Thirdly, the application of the pointing movement was presented. The present study introduced a kind of miniature detecting robots with multi-mode deployment. The robots can detect and collect the necessary and vital information in the target areas through human-computer interaction controlling and monitoring, which can provide the first hand information for decision-making. The efficiency of the human-computer interaction (HCI) is an important aspect of the robots for achieving their rapid response. The present study presented the behavioral science theoretical base of HCI interface design for the elderly adults. Moreover, the theoretical base of behavioral science for designing universal human computer interaction interface was presented. Furthermore, other related factors for designing HCI interface were also introduced and analyzed. Then, the universal HCI interface of the miniature detecting robots with multi-mode deployment was presented to raise the efficiency of human-computer interaction.

In addition, the findings of the speed matching interactions between visual and tactile motion could have important implication for researching bionic hand-eye coordination algorithm of intelligent robot. The visual speed stimuli can calibrate the tactile speed discrimination, but not vice-versa. Such an influence can be taken into account in designing multimodal control system, such as might be found in visual and tactile coordination of humanoid robot. The future work will focus on the basic theory of bionic visual and tactile coordination control algorithm for humanoid robot controlling.

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Chapter 1 Introduction

Summary

This chapter briefly introduces the background of the influence of visual information on tactile and kinesthetic perception. And then, two questions on influence of visual information on tactile and kinesthetic perception were presented. That is, the pointing movement under restricted visual feedback conditions and intermodal interactions between visual motion and tactile motion. Moreover, the related previous studies about the above mentioned two problems were expounded. Furthermore, the aim and contents of the thesis are also briefly described. The dissertation is composed of two experiments and an application design. The first experiment investigates the influence of aging on pointing movements under restricted visual feedback of hand movement and target location. The second experiment explores the speed discrimination interaction between visual and tactile motion with unimodal tasks and crossmodal tasks. In addition, the application of pointing movements was mainly researches the universal human computer interaction interface method of the miniature detecting robots with multi-mode deployment

1.1 Influence of visual information on touch

Our experience of the world is generally multimodal. To perceive our world, we make full use of multiple sources of sensory information derived from different modalities including visual, tactile, auditory, olfactory and gustatory system. Statistics suggest that as much as 80-90 percent of all perceptual information is received by the human brain from visual and tactile senses [1]. This shows that vision and touch are the most important source of perceptual information for human. Touch, for the most part, is a proximal sense. The sensations produced by the events, such as warm, movement and pressure information, are a function of the underlying morphology and physiology of the neural end organs that lie under or within the skin [2]. Therefore, touch usually can be classified into two major types, tactile perception (neural end organs within skin) and kinesthetic perception (neural end organs under skin).

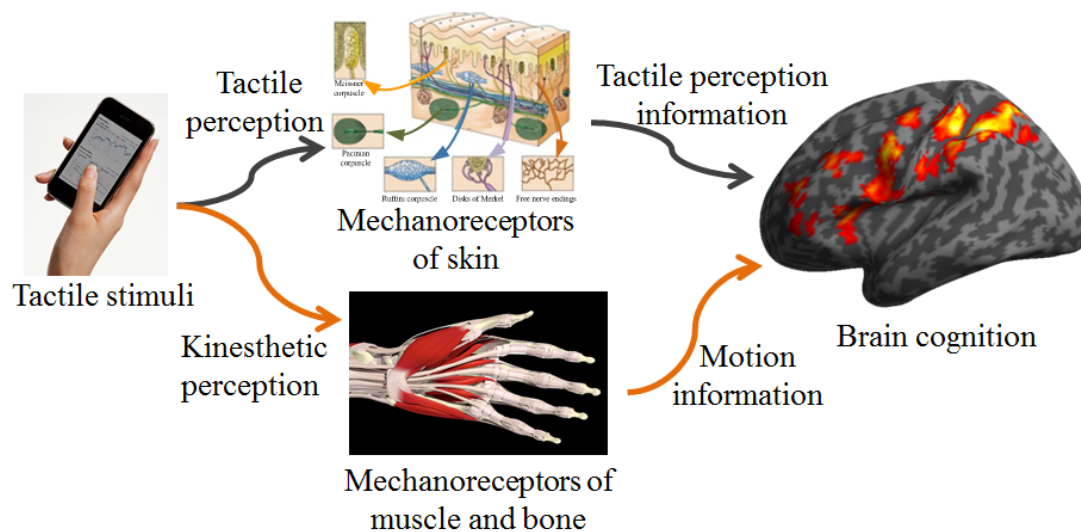


Figure 1.1 The generation mechanism of tactile perception and kinesthetic perception

Much evidences of previous researches have shown that human nervous system integrates signals from visual and tactile modalities to maximize the information available for perception and action[3]. In general, the tactile perception and kinesthetic perception about the environment is usually acquired by visual modality at

the same time. For example, to obtain the object information (size, shape, curvature, orientation), we should see and touch the object and then make a decision. Therefore, the vision plays an important role in human touch. The influence of visual information on tactile and kinesthetic perception has been the focus of an increasing number of studies in recent years. Two of the many aspects of the influence of visual information on touch increasingly fascinate and provoke the researchers. That is, the pointing movement under restricted visual feedback conditions and intermodal interactions between visual motion and tactile motion.

1.1.1 Influence of visual motion on tactile perception

The influence of visual motion on tactile perception has been the focus of an increasing number of studies in recent years. For example, the effect on the perceived reaction times for localizing of a stimulus presented in visual modality by the presentation of a second stimulus presented in a tactile modality has been examined. Gray and Tan [4] found that visual motion stimuli can lower reaction times for tactile localization despite the fact that the visual stimuli do not predict the location of the tactile stimuli. They suggested that a tactile map of external space can utilize direction and time to contact information from vision to reorient attention. They concluded that visual motion stimuli can direct tactile attention spatially. In another study involving visual motion stimuli, the effect of visual motion stimuli on judging the direction of visual motion has been examined [5]. When the visual motion was in a direction opposite to that of the tactile motion, subjects often erred and judged the motion to be in the direction of the visual stimulus rather than that of the tactile stimulus.

In generally, our experience in everyday is one of coordinating information from the various sensory channels, especially visual and tactile sensory channels [5]. Thus, intermodal interaction is a necessary result of various modalities information processing. In part as a function of recognizing the multimodal nature of much of

human perception, there is considerable interest in examining the interactions between information received from visual and tactile modalities. Thus, intermodal interaction between visual motion and tactile motion was attracting growing attention from researchers in recent years. The mutual enhancement and mutual distraction between vision and tactile motion have both been observed in these studies. When attending to vision, action comprehension is disrupted by the presentation of tactile information. While, some researchers have found that the reaction times are faster in response to visual-tactile motion than in response to either modality alone.

Pursuit and interception movements depend heavily on accurate speed judgments, particularly visual speed matching and tactile speed matching. Thus, speed matching is an important aspect of daily life. Although there are many researches on the intermodal interactions between visual motion and tactile motion, the speed matching interactions between visual motion and tactile motion are less studied. Whether there are interactions and how those intermodal interactions might affect visual speed discrimination and tactile speed discrimination are issues that remain unclear. These issues will be further elaborated and discussed in the following chapters.

1.1.2 Influence of visual feedback condition on kinesthetic perception

The influence of visual feedback condition on kinesthetic perception has been studied comprehensively for over one hundred years. The pointing movement is one of the most common human kinesthetic perceptions. In human pointing, spatial accuracy decreases as the speed of the movement increases, and the movement becomes slower as the need for accuracy increases. The early work of Woodworth [6] separated pointing movement into two phases known as the initial adjustment phase (i.e., movement planning) and the current control phase (i.e., on-line control) to examine the conditions that affected movement accuracy and began a long tradition of research on motor control under full visual feedback condition. His analysis model,

which is known as the planning-control model, has been examined and extended considerably over the years [7]. To the best of our knowledge, the most influential contribution to research on pointing movement were derived from Fitts [8], who was the first to propose a formal relationship between movement time (MT) and the index of difficulty (ID), which is $MT = a + b \cdot ID$ (where a and b are empirical constants; $ID = \log_2 (2A/W)$; W : the width of the target; and A : the distance from the starting point to the target). This equation was found to be so widely applicable that it became known as Fitts' law. Since Fitts' experiments, the relationship between the MT and ID has been replicated hundreds of times through a variety of tasks [7,9-12]. The conditions of these pointing movement have also extended constantly from full vision conditions to restricted visual feedback conditions of hand movement and target location [13-16]. Recently, a study by Brouwer and Knill [17,18] indicated that, when no visual information is available, humans can use information regarding location that they memorized while planning to move their hands to a target location.

Over the years, age-related differences in the goal-directed pointing movements also have attracted researchers interested in research of pointing movement. Compared to young adults, elderly adults presented slower motor responses and execution and a higher variability in their reaction and movement times [19-21]. In addition, how visual feedback of hand movement or target position can be used by older adults during arm movement was attracting growing attention from researchers in recent years. Together, all the above mentioned researches support the classical idea of a slower processing of information and slower movement time with age [21,22]. However, the elderly adults do not necessarily make lower information processing precision and the lower movement accuracy than young adults especially under restricted visual feedback of hand movement and target location [23,24]. Thus, how restricted visual feedback of hand movement and target location can be used by

elderly adults in the pointing movements remain to be investigated. These issues will be further elaborated and discussed in the following chapters.

1.2 The purpose of the present dissertation

The main aim of this thesis was to investigate the influence of visual information upon tactile and kinesthetic perception, especially investigate the effects of aging on pointing movements under restricted visual feedback conditions and the speed matching between tactile motion and visual motion. Moreover, the application of the pointing movement was also presented. To achieve these aims, two related experiments and one design were conducted.

1.3 The contents of the dissertation

This dissertation mainly investigates the influence of visual information upon tactile and kinesthetic perception. The dissertation contains descriptions of the two experiments and an application briefly introduced below.

Chapter 2 describes the first experiment, in which the speed matching between tactile motion and visual motion was investigated. The present study demonstrated reciprocal interactions between the processing of visual speed matching and tactile speed matching. The reciprocal interactions between visual and tactile speed matching modalities directly support the view that at some point in the motion processing stream, these two modalities have partially overlapping substrates.

Chapter 3 describes the second experiment, in which the effects of aging on pointing movements under restricted visual feedback conditions were investigated. Significant main effect of aging on movement times has been found. However, no significant main effects of age on the mean accuracy rate under condition of restricted visual feedback were found. The present study suggested that the elderly subjects

made a very similar use of the available sensory information as young subjects under restricted visual feedback conditions. Moreover, the study suggested that Fitts' law applied for pointing movements of the elderly adults under different visual restriction conditions. It presented a theoretical base of behavioral science for designing universal human computer interaction (HCI) interface.

Chapter 4 describes the application of the pointing movement. The present study introduces a kind of miniature detecting robots with multi-mode deployment. Then, the theoretical base of behavioral science for designing universal human computer interaction interface was presented. Moreover, other related factors for designing HCI interface are also introduced and analyzed. At last, the universal HCI interface of the miniature detecting robots with multi-mode deployment was presented to raise the efficiency of human-computer interaction.

Chapter 5 puts forward conclusions of the dissertation and future challenges.

Chapter 2 Speed Matching Interaction between Visual and Tactile Motion

Summary

The goal of the present study was to explore the speed discrimination interaction between visual and tactile motion during unimodal tasks and crossmodal tasks. Fifteen participants performed four speed reproduction tasks that included a tactile-tactile task, a visual-visual task, a tactile-visual task and a visual-tactile task at various speeds. Participants were asked to remember the standard stimuli speed and match the stimuli speed with the standard stimuli speed. The present study showed that both visual discrimination speed and tactile visual discrimination are underestimated relative to the standard speed at relatively high speeds during unimodal tasks. The present study suggests that speed matching is processed similarly in both the visual and tactile sensory systems. Moreover, the present study demonstrated reciprocal interactions between the processing of visual speed matching and tactile speed matching. Visual speed stimuli positively affected tactile speed matching, whereas tactile speed stimuli disrupted visual speed matching at relatively high speeds. Interestingly, visual speed stimuli can calibrate the tactile speed discrimination, but not vice-versa. A possible explanation is that the perceptual system is organized such that speed stimuli input from visual modalities receive a higher weight in the interaction process than speed stimuli input from tactile modalities. The reciprocal interactions between visual and tactile speed matching modalities directly support the view that at some point in the motion processing stream, these two modalities have partially overlapping substrates.

Keywords: Speed matching, Visual speed, Tactile speed, Crossmodal, Unimodal

2.1 Introduction

Speed matching is an important aspect of daily life. Pursuit and interception movements depend heavily on accurate speed judgments, particularly visual speed matching and tactile speed matching judgments. Both visual speed matching and tactile speed matching share the common problem of computing stimuli motion from a spatiotemporal pattern of activation across a two-dimensional sensory sheet (i.e., the retinas and the skin). A number of studies have investigated speed matching during visual motion stimuli or tactile motion stimuli [25-28]. Some studies have suggested that perceived visual speeds are increased when the overall visual stimulus is dense, either due to increasing the spatial frequency (i.e., $1/SP$ (spatial period) [periodic gratings]) or the number of items in the display [dot density] [25,27-29]. Consistent with visual speed estimates, tactile speed estimates are modified by the spatial frequency (dot spacing); however, tactile speed estimates are not modified by dot disposition (period, non-period) nor by dot density [26,30]. Smith and Edgar [28] also suggested that visual matching speed is underestimated relative to the standard speed at relatively high speeds. Much is known regarding the visual matching speed, although the relation between tactile matching speed and the standard speed remains obscure.

Our experience of the world is generally multimodal. Information regarding the speed of a moving object, for instance, can be conveyed tactually and visually. Research on multimodal interactions has formed the basis of speed matching interactions between visual and tactile motions. Intermodal interactions between visual motion and tactile motion have been the focus of an increasing number of studies in recent years. A common approach to the study of crossmodal motion perception is to examine the perception of motion stimuli presented via one modality

in the presence and absence of motion stimuli presented in another modality. Gray and Tan [4] measured reaction times for localizing tactile stimuli. They found that visual motion stimuli can lower reaction times for tactile localization despite the fact that the visual stimuli do not predict the location of the tactile stimuli. They suggested that a tactile map of external space can utilize direction and time to contact information from vision to reorient attention. In another study involving visual motion stimuli, subjects judged the direction of apparent motion, generated on a subject's fingerpad by stimulating two locations sequentially [5]. When the visual motion was in a direction opposite to that of the tactile motion, the subjects often erred and judged the motion to be in the direction of the visual stimulus rather than that of the tactile stimulus. The study favors the view that visual motion captures tactile motion.

Moreover, mutual enhancement between vision and tactile motion has been observed, and reaction times are faster in response to visual-tactile motion than in response to either modality alone [31]. The findings indicated that the motion signals of vision and touch are integrated in relatively low-level stages of perceptual processing. In contrast, a mutual distraction between vision and tactile motion also has been observed; when attending to vision, action comprehension is disrupted by the presentation of tactile information [32]. Additionally, in a recent review article, Soto-Faraco and Kingstone [33] presented data indicating that visual movement 'captures' touch and to a much greater extent than tactile movement captures visual movement.

Speed matching interactions between visual motion and tactile motion reflect important cognitive process of visual-tactile motion. Indeed, almost all everyday situations contain speed information of motion, and, accordingly, the failure to perceive speed of motion (the clinical syndrome of cerebral akinetopsia) renders everyday life tasks difficult and even dangerous [34]. Because speed information

pervades everyday life environments, it may be surprising to learn that past research on multisensory interactions rarely included speed matching interactions between visual motion and tactile motion for investigation. Whether there are interactions and how those intermodal interactions might affect visual speed discrimination and tactile speed discrimination are issues that remain unclear. Thus, the interaction of speed discrimination through speed matching of visual and tactile motion remains to be investigated.

In the present study, whether there are interactions and how those intermodal interactions might affect visual speed discrimination and tactile speed discrimination would be explored. Fifteen participants performed four speed reproduction tasks. The unimodal tasks included the following: a tactile-tactile task (T-T task) and a visual-visual task (V-V task). The crossmodal tasks included the following: a tactile-visual task (T-V task) and a visual-tactile task (V-T task). By comparing and analyzing the differences between the four tasks, the present study sought to elucidate the differences between tactile speed matching and visual speed matching, how tactile speed stimuli influence visual speed matching, and how visual speed stimuli influence tactile speed matching.

2.2 Methods

2.2.1 Subjects

Fifteen healthy young participants (all right-handed males) ranging in age from 22 to 25 years, with a mean age of 23 years, volunteered to participate in the experiment. Handedness was confirmed according to the Edinburgh Handedness Inventory [35]. All participants had normal vision and were asked to adjust speed by touching a tactile stimulator that was placed under their right middle fingertips (D3) or to observe dots presented on the computer screen. All subjects were unaware of the

purpose of the study. The experiment obtained written informed consent from all subjects before the experiment. The study was approved by the ethical committee of Okayama University, Japan. Moreover, the experiments are in accordance with the Declaration of Helsinki.

2.2.2 Apparatus and stimuli

The experimental apparatus is shown schematically in Figure 2.1a. The device consisted of a visual monitor (Figure 2.1b), a tactile stimulator (Figure 2.1c), a jaw pedestal, and speed adjustment keys. There were three speed adjustment keys, a decision key, a speed decreasing key, and a speed increasing key. As shown in Figure 2.1b, the visual stimuli (30 mm in length and 20 mm wide) were presented on a black background at the center of a monitor.

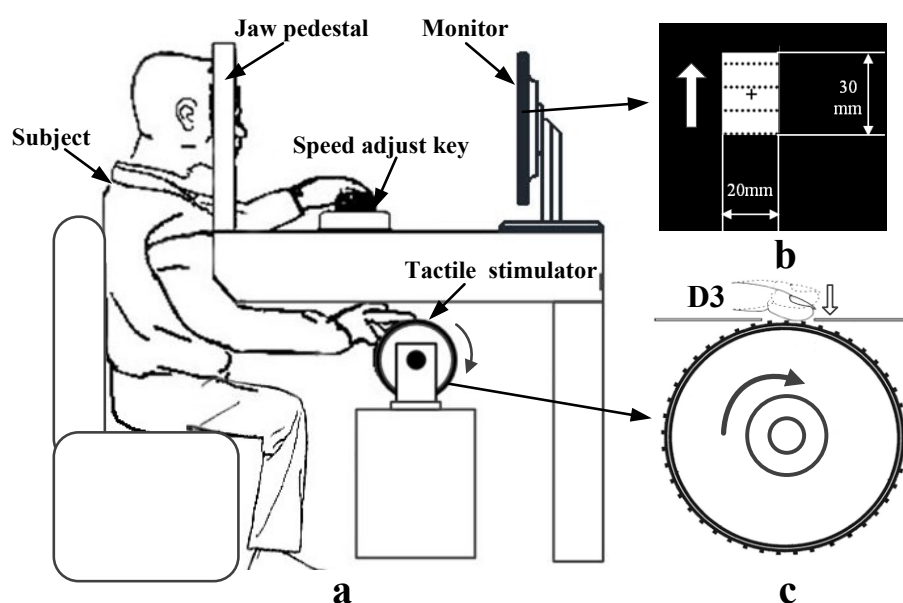


Figure 2.1(a) A depiction of the experimental apparatus and the position of the participant. The participants were seated in front of a table with their heads stabilized in a head and chin rest (jaw pedestal). The participants observed tactile stimuli presented by the tactile stimulator with the index fingers of their right hands. Participants were required to remember the standard stimulus speed and to adjust the matching stimulus speed to the standard stimulus speed with the speed adjust keys. **(b)** Parameters of the visual speed matching display. The visual stimulus was

presented at the center of a visual monitor over a black background. Visual stimuli consisted of periodic dots that corresponded to those of the tactile stimulators. (c) The tactile stimulator.

The stimuli were composed of periodic dots that corresponded to the tactile stimulators. The visual and tactile stimuli always moved from the bottom to the top for all tasks. The black background of the monitor was intended to prevent the participants from viewing the stimulator. A static crosshair was placed at the center of the monitor during tasks that did not employ visual stimulation. As shown in Figure 2.1, the tactile stimulator was similar to that described by Zompa & Chapman[36]; cylindrical drums with circumferences of 400 mm and thicknesses of 20 mm were mounted on a drive shaft. Periodically spaced raised dots covered the surfaces of the drums. These dots were 1 mm in diameter on the top and 1 mm high; the transverse spatial period (SP) (i.e., the center-to-center distances between adjacent dots in each row) was 2 mm, the longitudinal spatial period (SP) (i.e., in the direction of the scan) was 8 mm, and the density 6.3 dots/cm².

2.2.3 Procedure and task design

As shown in Figure 2.2(a-d), the participants performed four tasks that included a tactile-tactile task (T-T task), a tactile-visual task (T-V task), a visual-tactile task (V-T task), and a visual-visual task (V-V task). Each trial contained two stimuli. Participants were required to remember the standard stimulus speed (SSs) and to adjust the matching stimulus speed to the standard stimulus speed using the speed adjust keys. When participants perceived the speed to be the same as the SS, they pressed the decision key to indicate the matching speed (MSs). There were six SSs: 20, 40, 60, 80, 100, and 120 mm/s. There were seven matching stimulus speeds, three of which were slower than the presented SS presented, three were larger, and one was identical to the SS. MSs were randomly presented. The participants were informed that the tactile stimulator would be moved under D3 at different speeds and that the

dots displayed on the computer would move from the bottom to the top.

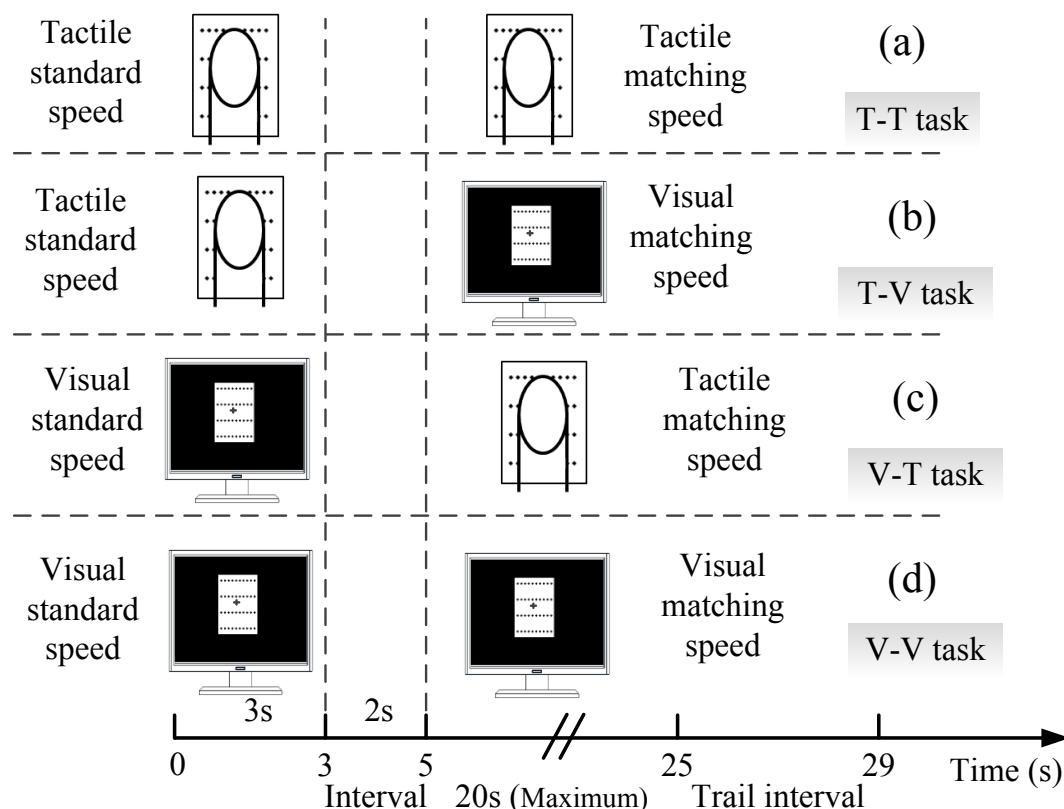


Figure 2.2 The four tasks used in this experiment. Participants performed four tasks in this experiment that included a T-T task, T-V task, V-T task and a V-V task. Each trial contains two stimuli. Participants were required to remember the standard stimulus speed and to adjust the matching stimulus speed to the standard stimulus speed with the speed adjust keys. In all tasks, the standard speed stimuli were presented for 3 s. After a 2 s delay, the matching stimuli speed was presented for a maximum of 20 sec. During this time, the participants adjusted the speed by pressing the speed increase or speed decrease keys until they perceived the speed of the stimuli as equal to the SS, at which point, they pressed the decision key to indicate the MS.

As shown in Figure 2.2a, the SS and MS were both presented by the tactile stimulator in the T-T task. The SS continued for 3 s. After a 2 s delay, the matching stimulus speed was presented for a maximum of 20 sec. During this time, the participants adjusted speed by pressing the speed increase or speed decrease keys until

they perceived the speed of the stimuli as equal to the SS, at which point, they pressed the decision key to indicate the MS. MSs were recorded using a computer. The speeds were increased by 5 mm/s after pressing of the increase speed key and were decreased by 5 mm/s after pressing of the decrease speed key. As shown in Figure 2.2b, the procedure for the T-V task was identical to that of the T-T task with the exception that the SS was presented by the tactile stimulator, and the MS was presented by the visual stimulator. Similarly, as shown in Figure 2.2c and Figure 2.2d, the V-T and V-V tasks were identical to the T-T task with the exception of the stimulating modalities of the SS and MS. The SS was presented using the visual stimulator, and the MS was presented using the tactile stimulator in the V-T task, whereas the SS was presented using the visual stimulator, and the MS was also presented using the visual stimulator in the V-V task. Every participant performed each task 60 times, and they were given a 4 s break after every 20 trials. Thus, each participant performed a total of 240 trials across all four tasks.

2.2.4 Data acquisition and analysis

The task and data acquisition were controlled using a computer. The SS speed was recorded for each trial. The MS was entered by the experimenter and stored with the trial. The intertrial intervals were controlled using the computer. Statistical analyses consisted of parametric tests for data that were normally distributed (as determined by the Shapiro-Wilk normality test) and showed similar variances. A speed (six speeds) x task (four tasks) repeated measures ANOVA on mean matching speeds was performed. Additionally, paired t-tests using the Bonferroni correction ($\alpha = .05$) were used to reveal differences among the four tasks. To describe the relationships between MSs and SSs, linear regression analyses were applied to the data obtained from each subject. The level of significance was fixed at $P < 0.05$.

2.3 Results

2.3.1 Linear relationships

All participants were able to match the standard speed and showed monotonic relationships between MSs and SSs (linear regression, $P < 0.0001$). The mean MSs of the 15 participants (from the 60 trials of each task) are plotted as a function of SSs in Figure 2.3(a-d). The mean MSs increased linearly as a function of the SSs in all tasks. A regression analysis of the mean estimates yielded significant r^2 values of .96, .88, .95, and .99, for the T-T, T-V, V-T and V-V tasks, respectively (T-T task: $F(1, 88) = 2295.54$, $P < .0001$; T-V task: $F(1, 88) = 647.78$, $P < .0001$; V-T task: $F(1, 88) = 1669.15$, $P < .0001$; and V-V task: $F(1, 88) = 2511.26$, $P < .0001$).

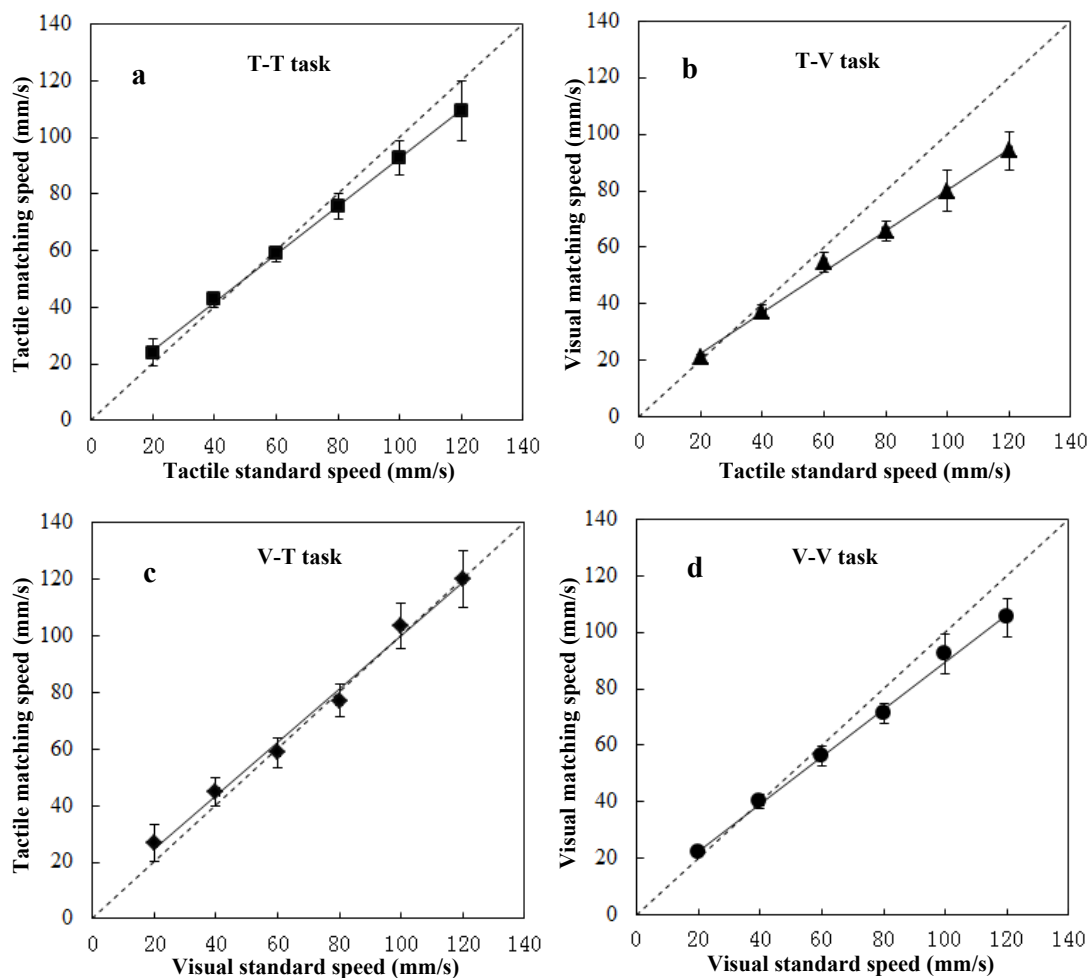


Figure 2.3 The mean matching speeds from the 15 participants (60 trials per task) as a function of

the standard for the T-T, T-V, V-T and V-V tasks are plotted. The black solid lines represent the best-fitting linear functions for average matching speed. The dash lines indicate the standard speed of the stimuli. The error bars represent the standard errors of the mean (SEM). The linear functions calculated for the T-T and V-V tasks exhibited similar slopes. Moreover, the speed matching functions were also linear for the T-V and V-T tasks. The slope for the V-T task was greater than those of the T-T and V-V tasks. However, MSs were greatly underestimated in the T-V task.

The y-intercepts (i.e., the constants) and slope coefficients (i.e., the b constants) of the linear relationships of all tasks were as follows: T-T task, $MS = 7.90 + 0.85 SS$; T-V task, $MS = 8.34 + 0.72 SS$; V-T task, $MS = 5.89 + 0.94 SS$; and V-V task, $MS = 5.96 + 0.84 SS$. The linear functions calculated for the T-T and V-V tasks exhibited similar slopes. Moreover, the speed matching functions were also linear for the T-V and V-T tasks. The slope for the V-T task was greater than those of the T-T and V-V tasks, whereas the slope for the T-V task was smaller than those of the T-T and V-V tasks.

2.3.2 Mean matching speeds

A speed (six speeds) $\times$ task (four tasks) repeated measures ANOVA on mean matching speeds was performed. The present study found significant main effects of speed, $F(5, 70) = 63.74$, $P < .0001$, and task, $F(3, 42) = 24.90$, $P < .0001$, on mean matching speeds. Moreover, the present study found a significant interaction between speed and task, $F(15, 210) = 7.04$, $P < .0001$. To determine the significance of the differences in MS across the four tasks and six speeds, the present study performed in the present study multiple comparisons using the Bonferroni correction ($\alpha = .05$). As shown in Figure 2.4, there were no significant differences between the T-T and V-V tasks at speeds of 20, 40, 60, 100 and 120 mm/s ($P > .05$). Moreover, the present study found that the MSs in V-T task were more accurate than the MSs in the T-T task at speeds of 100 and 120 mm/s ($P < .05$) and the MSs in the V-V task at speeds of 80, 100

and 120 mm/s ($P < .05$). Furthermore, the present study found that the MSs in the T-V task were less accurate than the MSs in the T-T task at speeds of 80, 100 and 120 mm/s ($P < .05$). The MSs in the T-V task were also less accurate than the MSs in the V-V task at speeds of 100 and 120 mm/s ($P < .05$).

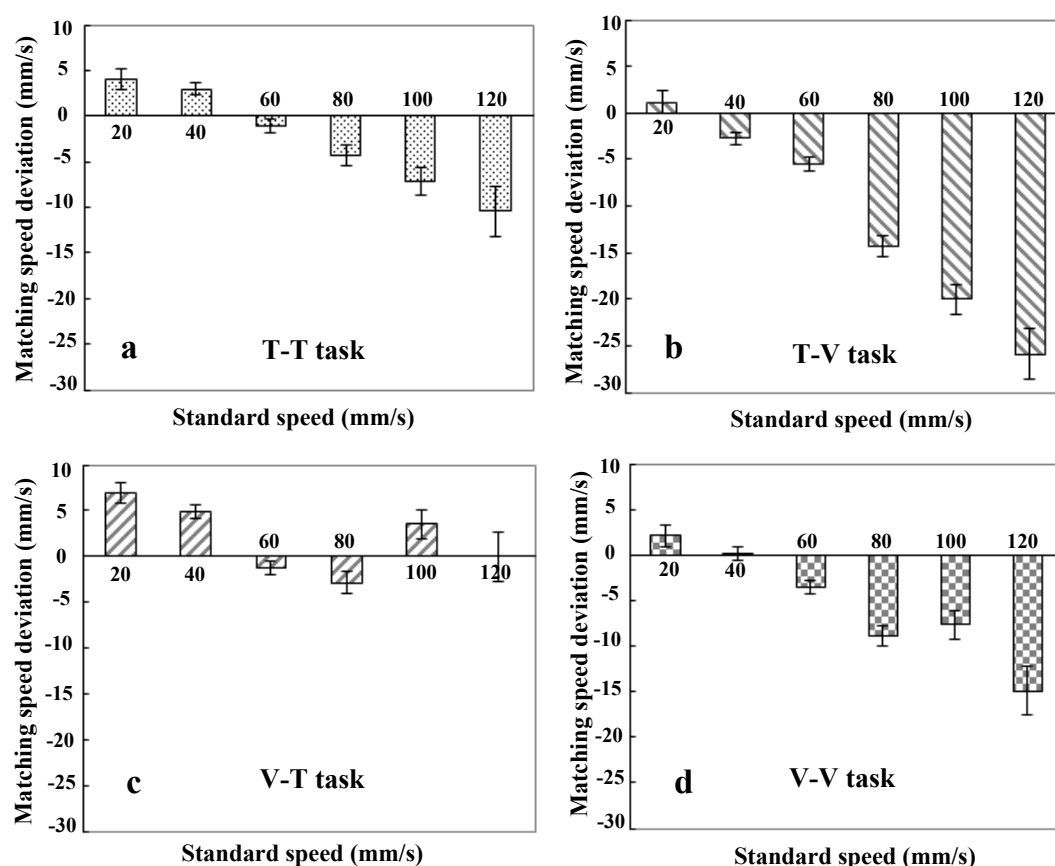


Figure 2.4 Matching speed deviations for the T-T, T-V, V-T and V-V tasks. A speed (six speeds) $\times$ task (four tasks) repeated measures ANOVA on mean matching speeds was performed. The error bars represent the standard errors of the mean (SEM). Significant main effects of speed and task on mean matching speeds was found. Moreover, the present study also found a significant interaction between speed and task.

2.4 Discussion

The present study used speed reproduction tasks to measure the apparent relative speeds of visual, tactile, tactile-visual and visual-tactile stimuli moving at various

speeds. The study yielded three main results. First, the present study showed that not only visual matching speeds but also tactile matching speeds are underestimated relative to actual speeds at relatively high speeds. This finding suggests that speed matching is processed similarly in both the visual and tactile sensory systems. Second, reciprocal interactions between the visual speed modality and the tactile speed modality were found in the present study. The visual speed stimuli facilitated the perception of tactile speed matching, whereas the tactile speed stimuli may have disrupted visual speed matching. Third, the present study directly supports the view that at some point in the motion processing streams, the visual and tactile speed modalities have partially overlapping substrates.

2.4.1 Speed matching in the unimodal tasks

As shown in Figure 2.3a and Figure 2.3d, the speed matching functions were linear in both the T-T and V-V tasks. However, matching speeds were underestimated in both tasks (i.e., the slopes were less than 1). At low speeds, the estimates were accurate, but as the standard speed increased, the match speeds increased less than the standard speeds. Thus, at high speeds, matching speeds are underestimated relative to the standard speed. The linear functions of the T-T and V-V tasks exhibited similar slopes, indicating that the relationships between the SSs and the MSs, were similar in these two tasks. Moreover, as shown in Figure 2.4a and Figure 2.4d, there were no significant differences between the T-T and V-V tasks. Smith and Edgar [28] suggested that visual matching speeds are underestimated relative to standard speeds at relatively high speeds. The present study corroborated this suggestion and extended it to tactile speed matching. The tactile matching speeds are also underestimated relative to standard speeds at relatively high speeds. The present study suggested that speed matching is processed similarly in the visual and tactile sensory systems.

2.4.2 Speed matching in the crossmodal tasks

As shown in Figure 2.3 and Figure 2.4, the MSs in the V-T task were more accurate than the MSs in V-V task at speeds of 80, 100 and 120 mm/s. In the V-V and V-T tasks, the SSs were both presented by the visual stimulator, and the MSs were presented by the visual and tactile stimulators, respectively. Thus, the visual stimuli were identical across these tasks. The subjects based their decisions on the same visual stimuli in these two tasks. The greater accuracy obtained in V-T task showed that tactile reproductions of the speed of visual stimuli were more accurate than visual reproductions of the same stimuli at relatively high speeds. As shown in Figure 2.4, the MSs in the V-T task were more accurate than the MSs in T-T task at speeds of 100 and 120 mm/s. In the T-T and V-T tasks, the SSs were presented by the tactile stimulator and visual stimulator, respectively, but the MSs were both presented by the tactile stimulators. Thus, the tactile stimuli were identical across the two tasks. The greater accuracy obtained in V-T task showed that tactile reproductions of the speed of visual stimuli were more accurate than tactile reproductions of tactile stimuli at relatively high speeds. In summary, the MSs in the V-T task were more accurate than those in the unimodal tasks (T-T task and V-V task) at relatively high speeds. The present study has showed that not only visual matching speeds but also tactile matching speeds are underestimated relative to actual speeds at relatively high speeds in the unimodal tasks. Therefore, the present study suggested that there are speed perception interactions between visual speed stimuli and tactile speed matching. The visual speed stimuli had a positive effect on tactile speed matching, especially at relatively high speeds.

Moreover, as shown in Figure 2.3, the slopes of the MS-SS function in the T-V task were markedly less than one (indicating underestimations of the SSs). The MSs in the T-V task were less accurate than those in the T-T task at speeds of 80, 100 and

120 mm/s. In the T-V and T-T tasks, the SSs were both presented by the tactile stimulator, but the MSs were presented by the visual and tactile stimulator, respectively. The subjects based their decisions on the same tactile stimuli in these two tasks. The decreased accuracy obtained in T-V task indicated that visual reproductions of tactile speed stimuli are less accurate than tactile reproductions of the same stimuli, especially for tactile speeds of 80, 100 and 120 mm/s. As shown in Figure 2.3 and Figure 2.4, the MSs in the T-V task were also less accurate than those in the V-V task at speeds of 100 and 120 mm/s. In the T-V and V-V tasks, the SSs were presented by the tactile stimulator and visual stimulator, respectively, but the MSs were both presented by the visual stimulators. Thus, the visual stimuli were identical across the two tasks. The less accuracy obtained in T-V task showed that visual reproductions of the speed of tactile stimuli were less accurate than the visual reproductions of same stimuli at relatively high speeds. In summary, the MSs in the T-V task were less accurate than those in the unimodal tasks (T-T task and V-V task) at relatively high speeds. The present study shows that not only visual matching speeds but also tactile matching speeds are underestimated relative to actual speeds at relatively high speeds in the unimodal tasks. Therefore, the present study suggests that there are speed perception interactions between tactile speed stimuli and visual speed matching. The tactile speed stimuli disrupted visual speed matching, especially at relatively high speeds.

The present study demonstrated reciprocal interactions between the processing of visual speed matching and tactile speed matching. Visual speed stimuli positively affected tactile speed matching, whereas tactile speed stimuli disrupted visual speed matching at relatively high speeds. Interestingly, visual speed stimuli can calibrate the tactile speed discrimination, but not vice-versa. Possible explanations for crossmodal asymmetries between visual and tactile speed matching processing are detailed below.

The perceptual system is organized such that speed stimuli input from visual modality will receive a higher weighting in the interaction process than speed stimuli input from tactile modalities. Some researchers have argued that humans may have an inherent bias to attend to visual motion. The results of these studies showed that visual motion stimuli significantly positively influenced the localization tactile motion and audition, tactile motion stimuli influenced audition and aural stimuli influenced tactile motion [4,5,37]. This dominance of vision in the domain of motion is in agreement with the data presented here. In the V-T task, the SSs were presented using a visual stimulator, and the MSs were presented using tactile stimulators. The subjects based their decisions on the tactile stimuli in this task. However, in the T-V task, the SSs were presented using a tactile stimulator, and the MSs were presented using visual stimulators. The subjects based their decisions on the visual stimuli in this task. For visual speed matching, the visual speed of a contrast moving across the retina is signaled based on the spatial distance separating the two receptors and the temporal interval between their separate excitations [27]. In contrast, tactile speed matching depends on sensory feedback from tactile mechanoreceptors, including Pacinian (PC), rapidly adapting, glabrous skin (RA), and slowly adapting afferents (SAI and II), to compute and minimize slip [38-42]. Some studies have suggested that the motion effects generated across the retina by visual motion stimuli last longer and are clearer than the motion effects generated by tactile mechanoreceptors in response to tactile motion stimuli [43]. Indeed, if input in one modality is presented at a higher intensity or has a better “quality” of information than input in another modality, the interaction process may be biased by more salient input [33]. Thus, the SSs may significantly influence the tactile speed matching motion in the V-T task. The better “quality” of the speed motion signal originating from the visual system boosted the tactile motion signal by an amount determined by the visual speed stimulus. In contrast, the worse

“quality” of the speed motion signal originating from the tactile system disrupted the visual motion signal by an amount determined by tactile speed stimulus. Konkle et al. [44] used asynchronous stimulus presentation and demonstrated that touch can affect the perception of visual motion. The present study corroborated this suggestion and extended it to tactile-visual speed matching. Furthermore, the present study interpreted the reciprocal interactions between visual and tactile speed matching as evidence that there are special filters tuned to specific stimulus properties [45], and the state of these filters determines how subsequently presented stimuli are processed. Recent neuroimaging findings have also demonstrated both strong activation of tactile motion processing areas by visual stimuli and activation of visual motion processing areas by tactile stimuli; these results imply that the two modalities have partially overlapping substrates [33,46-49]. The reciprocal interactions between visual and tactile speed matching modalities observed in the present study directly support the view that at some point in the motion processing streams, these two modalities have partially overlapping substrates.

2.5 Conclusion

This finding suggests that speed matching is processed similarly in both the visual and tactile sensory systems. Second, reciprocal interactions between the visual speed modality and the tactile speed modality were found in the present study. The visual speed stimuli facilitate the perception of tactile speed matching, while the tactile speed stimuli may have disrupted visual speed matching. Thirdly, the present study directly supports the view that at some point in the motion processing streams, the visual and tactile speed modalities have partially overlapping substrates.

Chapter 3 Effects of Aging on Pointing Movements under Restricted Visual Feedback Conditions

Summary

This chapter aims to investigate the effects of aging on pointing movements under restricted visual feedback of hand movement and target location. Fifteen young subjects and fifteen elderly subjects performed pointing movements under four restricted visual feedback conditions that included full visual feedback of hand movement and target location (FV), no visual feedback of hand movement and target location condition (NV), no visual feedback of hand movement (NM) and no visual feedback of target location (NT). This study suggested that Fitts' law applied for pointing movements of the elderly adults under different visual restriction conditions. Moreover, significant main effect of aging on movement times has been found in all four tasks. The peripheral and central changes may be the key factors for these different characteristics. Furthermore, no significant main effects of age on the mean accuracy rate under condition of restricted visual feedback were found. The present study suggested that the elderly subjects made a very similar use of the available sensory information as young subjects under restricted visual feedback conditions. In addition, during the pointing movement, information about the hand's movement was more useful than information about the target location for young and elderly subjects.

Keywords: Pointing movement, Aging, Visual restriction, Fitts' law, Movement time

3.1 Background

Many studies have researched the concept of the speed-accuracy trade-offs by using goal-directed pointing movement [50-52]. The predominant model employed in researching the speed-accuracy trade-offs was proposed by Fitts [8], who was the first to propose a formal relationship between movement time (MT) and the index of difficulty (ID). The ID-MT linear relationship was called Fitts' law. The y-intercept of the linear regression is an important parameter in Fitts' law. Ideally, the y-intercept should be zero for the intuitive reason that a movement rated at ID=0 should not take any time to complete. However, when Fitts' equation was first proposed, Fitts has also suggested different views that the y-intercept should not be zero or less than zero movement time owing to the natural variability of human performance. [53,54]. There is no consensus on the source of the non-zero y-intercept might be due to none of the existing explanations is satisfactory [for review, see 55]. Moreover, the slope of the regression line is also an important parameter in Fitts' law. Zhai [56] shows that the slope reciprocal yields values of 8.197 bps through analyzing all data from Fitts' [8] paper. However, the previous researches have also presented the value of the slope of the regression line in their discrete pointing tasks which were smaller than that observed in the classical Fitts' task [16,57,58]. Since the ID-MT linear relationship was first proposed, numerous researches regarded the intercept and the slope of linear regression as important parameters to test whether Fitts' law apply for their movement conditions [for review, see 55]. Since Fitts' law firstly confirmed the applicability of rapid-movement, it has been confirmed to hold for rotational movements, prehension movement, and foot movements, except for imagined pointing movements [59-65]. The conditions of these rapid-aiming movement have also extended constantly from full vision conditions to restricted visual feedback conditions of hand movement and

target location [13-16].

As a common Fitts' task, the goal-directed pointing movements toward visual targets are controlled by the processing information relative to the target location and hand's movement [66]. It has been consistently found that combined visual and proprioceptive encoding of the initial hand position improves the ability of the young adults to plan goal-directed movements compared to proprioceptive encoding alone [67]. Moreover, the young subjects are generally more accurate when they can see the target throughout the arm movement than when vision of the target is extinguished near movement onset [51]. This suggests that visual information is continuously processed to update the internal representation of target location in order to obtain higher movement accuracy. In addition, there are some researches attempt to compare the contributions of visual information of hand and target position in goal-directed movement. Carlton [13] found that movement accuracy of the young adults decreased to a greater extent when vision of the hand was withdrawn than when vision of the target was precluded at the arm movement onset. However, these results were not confirmed by Sarlegna and his colleagues [15] who found visual information relative to hand position may be less contributive than target location in online control of the goal-directed arm movement.

Over the years, age-related differences in the goal-directed pointing movements also have attracted researchers interested in research of speed-accuracy trade-offs [21,50,68]. Compared to young adults, elderly adults presented slower motor responses and execution and a higher variability in their reaction and movement times [19-21]. The well-documented declines in proprioception with aging may prevent elderly subjects from fast updating their movement plan [69,70]. The aging process has also been associated with the idea of a general slowing of information processing [21,50]. For instance, Briggs et al [71] have reported that age was associated with

prolongation of response time of processing of visual stimuli in simple perception tasks. In addition, how visual feedback of hand movement or target position can be used by older adults during arm movement was attracting growing attention from researchers in recent years. Haaland et al [14] suggested that the control of arm movements in the elderly relies more on online visual feedback of hand position compared to young adults, allowing older adults to compensate for planning deficiencies. On the other hand, Sarlegna [72] investigated the effects of aging on the contribution of target visual feedback to the online control of aiming movements. While the slowing of feedforward, age-related planning processes has been well built, the study highlighted the impairment of elderly adults to monitor the trajectory of online movement through visual feedback processes, which supports the earlier findings summarized by Owsley [for review, see 73]. Together, all the above mentioned researches support the classical idea of a slower processing of information and slower movement time with age [21,22]. However, the elderly adults do not necessarily make lower information processing precision and the lower movement accuracy than young adults especially under restricted visual feedback of hand movement and target location [23,24]. Thus, how restricted visual feedback of hand movement and target location can be used by elderly adults in the pointing movements remain to be investigated. Moreover, the existing evidence for Fitts' crucial finding that age-related decrease of movement speeds are related to the target size and the distance between targets under full vision conditions directly [22,74,75]. For example, Temprado and his partner [75] have confirmed that Fitts' law is robust for both ID manipulations in young and elderly. Recently, Giuffrida et al [76] further investigated the relationship of movement times of the elderly adults to the task complexity across Fitts' task under no vision conditions. The study found that movement time was longer for the no vision conditions whereas conversely reaction

time was shorter in the no vision conditions. The Fitts' tasks are mainly controlled by the processing information relative to the target location and hand's movement [66]. The relationship of movement times of the adults to the size of target and the distance between targets which considering the restricted visual information of hand movement or target location used is still to be investigated. Thus, whether Fitts' law applied to the elderly adults under restricted visual feedback of hand movement and target location will be tested.

The goal of this study was to investigate the effects of aging on pointing movements and test whether Fitts' law applied to the elderly adults under restricted visual feedback of hand movement and target location. In this study, 15 young subjects and 15 elderly subjects were asked to perform pointing movements while holding a stylus under different visual feedback conditions that included full visual feedback of hand movement and target location (FV), no visual feedback of hand movement and target location condition (NV), no visual feedback of hand movement (NM) and no visual feedback of target location (NT). Using these four conditions, the present study compared the pointing movement performances of the two age groups with and without visual feedback regarding hand movement or/and target location and analyzed the similarities and differences of the performance of the two age groups under the four conditions of restricted visual feedback. Then, the present study attempted to draw the effects of aging on pointing movements under restricted visual feedback conditions.

3.2 Methods

3.2.1 Participants

Fifteen elderly volunteers ranging in age from 60 to 78 years (mean age of 69.1, SD 5.3) and fifteen young controls ranging in age from 22 to 25 years (mean age of

22.9, SD 0.9) were recruited and voluntarily participated in this study. All of the volunteers were right-handed according to the Edinburgh Handedness Inventory [35], had normal or corrected-to-normal vision, were healthy with no past history of neurological disease and did not suffer from confusion, general mental deterioration or psychiatric disorders. In addition, all of the subjects were unaware of the purpose of the study. The study obtained written informed consent from all subjects before the experiment. The study was approved by the ethical committee of Okayama University, Japan.

3.2.2 Apparatus and stimuli

The experimental setup was an improved version of the experimental setup used by Yang, Wu & Honda, [77]. Both of these experimental setups were modified from the setup used 40 years ago [78,79]. The experimental setup was schematically represented in Figure 3.1. The device consisted of a color touch monitor (Touch TEK Corporation. Graphic properties: 19-inch, 1280 x 1024 pixels, 75 Hz; Touch properties: spatial accuracy is 0.294 mm, response time is 8 ms) and a piece of switchable light control glass (Nippon Sheet Glass Company, Ltd: 470 x 400 mm). The light control glass is a type of smart glass consisting of a multilayered composite with a liquid crystal sheet in the middle. When an electrical charge is delivered, the light passing through the glass is blocked for 0.03 ms. The light control glass was fixed horizontally above the touch monitor and was angled to approximately 30 degrees from the horizontal to facilitate observation for elderly subjects. The participants always viewed the stimulus on the touch monitor through the light control glass and pointed to the touch monitor with a stylus located under the glass. The targets were presented on either the touch monitor or the light control glass depending on the experimental condition.

3.2.3 Design and procedure

As shown in Figure 3.1, the participants were seated in front of a table with their heads stabilized in a head and chin rest, with a blindfold covering the left eye. The present study used monocular pointing movement tasks on account of the geometrical double-deck configuration of the device. The pointing targets were presented on the touch monitor or on the light control glass. The target stimuli and starting location consisted of a contour of the rectangular digital graphics, presented at the center of the touch monitor. The target and the starting location were outlined in black. The touch monitor display area uses a white background. As shown in Figure 3.2, the widths of the starting location were the same as the targets. They were separated (center to center) by specific distances. One of three target widths (W: 12.7, 25.4, and 50.8 mm) was combined with one of three distances (A: 50.8, 101.6, and 203.2 mm) in each trial. The widths and the amplitudes of the targets used in the present experiment were equal to IDs of 1, 2, 3, 4, and 5.

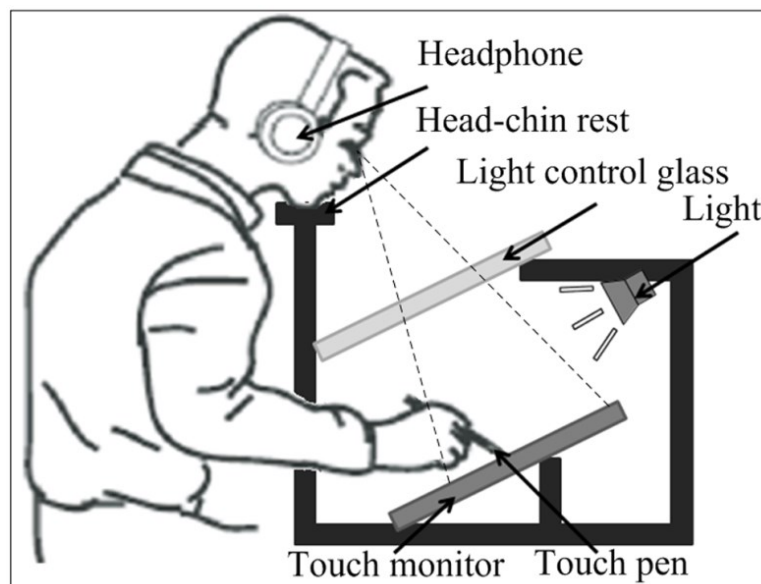


Figure 3.1 Depiction of the experimental device and the position of the subject. Subject sat approximately 70 cm from the screen. Visual stimuli were presented on the front screen. Auditory

stimuli were randomly presented at one of four locations using speakers (front 0°, right 90°, back 180°, and left 270°).

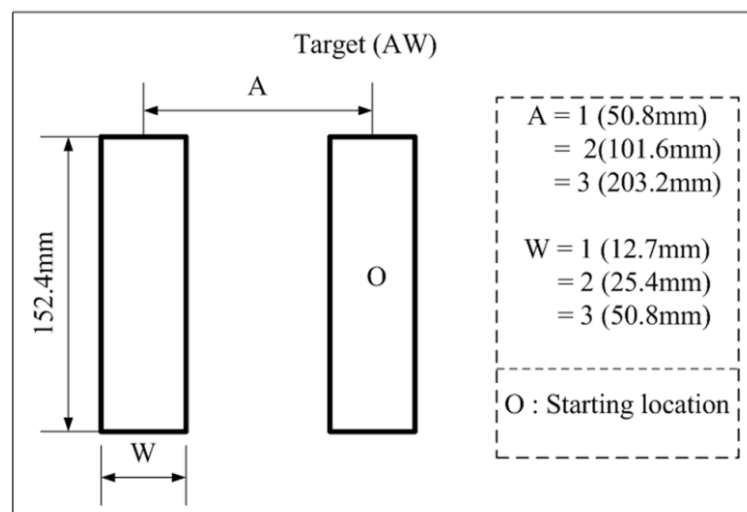


Figure 3.2 The size and shape of the target for leftward pointing trials. The position of the starting point was at the center of right rectangular digital graphics. One of three target widths (W: 12.7, 25.4, and 50.8 mm) was combined with one of three distances (A: 50.8, 101.6, and 203.2 mm) in each trial. The amplitudes and widths of the targets used in the present experiment corresponded to IDs of 1, 2, 3, 4, and 5.

Participants were instructed to place the stylus tip at the starting location with their right hand and then to point to the target as quickly and accurately as possible after a cue tone in a dark room. They could practice the pointing movement of each tasks 10 times prior to starting. As shown in Figure 3.3, during the FV trials, the participants were able to see their hand movement, the starting point and the target location. The trial was initiated when the participants placed the tip of the stylus at the starting point. When the stylus tip was in place for 5-s, pointing was cued by a 3000-Hz tone (100 ms) delivered via headphones. During the 5-s waiting period, the participants were allowed to look at their hand's position and the target location. Each trial finished after the stylus tip was removed from and subsequently contacted the

touch monitor (whether on or away from the target stimulus). The movement time (MT) was measured as the time between the removals of the stylus tip from the starting point to the time it reached the target point. The FV condition was used as the control condition. The NM, NT, and NV conditions were the same as the FV condition except that the visibility of the target location or the hand movement was controlled with the light control glass or the touch monitor during pointing. In the NM task, a transparent film printed with the target stimuli was placed on the light control glass. The actual target stimulus was presented on a touch monitor that was visible from the monocular viewing angle of the participants. The visual position and size of the target stimuli were consistent with the actual target stimulus. The monocular viewing angle of the design makes the participants feel that the projection of target on the light control glass superpose the target on the touch monitor. Then, the light control glass was turned off to block the visual information after the cue tone. Consequently, the participants could see the target location being presented on the light control glass, but they could not see their hand movements under the light control glass during pointing movement. Under NT condition, the actual target stimulus was presented on a touch monitor. However, it will be disappeared when the cue tone was delivered. In this condition, the target was no longer presented on the light control glass. The participants were only able to see their hand movements during pointing process. The NM condition and the NT condition were designed to test how hand's movement and target location feedback, respectively, influenced the performance of the two age groups. Under the NV condition, the participants were unable to see the hand movements and the target location when the cue tone was presented. The NV condition was designed to test the age influence on pointing movements when there was no visual feedback. After the practice trials, all of the participants performed 45 or more trials per task (3 widths x 3 amplitudes x 5 times); the task ended when the

computer recorded five correct pointing movements (i.e., hitting the target stimuli) for each ID.

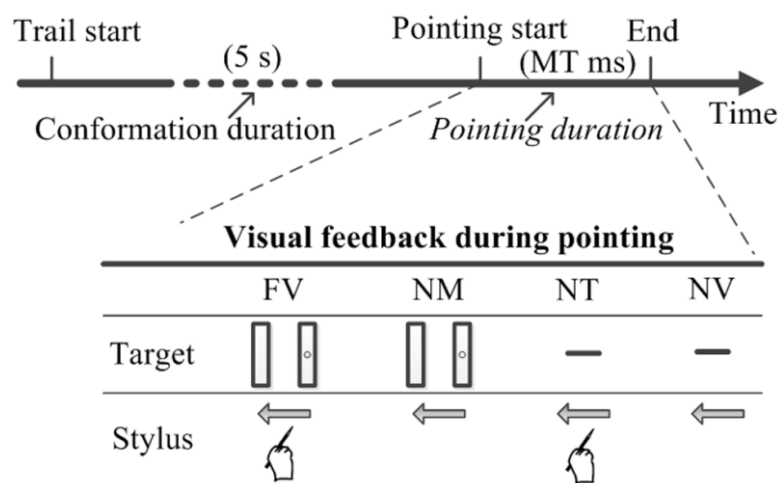


Figure 3.3 Time chart and visual feedback for one trial under the four pointing conditions. As shown in the table, the participants of the two age groups received visual feedback regarding either the target and their hand movement in the FV task, only the target in the NM task, only their hand movement in the NT task, or neither target location nor hand movement in the NV task.

3.2.4 Data analysis

The task and data acquisition were under computer control. The movement times (MTs) and target locations were recorded using a computer for all of the participants. Statistical analyses consisted of parametric tests for data that were normally distributed (as determined by the Shapiro-Wilk normality test) and showed similar variances. The present study performed a task (four tasks) x ID (five levels) x age (two groups) repeated measures analysis of variance (ANOVA) on the mean accuracy rates and the mean MTs, in which task and ID were used as within-subject factors and age as a between-subject factor. To describe the relationship between MTs and ID, linear regression analyses were applied to the data obtained from the two age groups. The level of significance was fixed at $p < 0.05$.

3.3 Results

3.3.1 Control of accuracy

The accuracy rates of the two age groups for the four pointing tasks have been calculated to investigate the aging effects on accuracy in pointing movement under restricted visual feedback of hand movement and target location. The mean accuracy rate was a ratio of the number of trials in which the tip of the stylus touched the target and the total number of trials for each task. The mean accuracy rates for young group and elderly group as a function of the index of difficulty for all pointing tasks. The mean accuracy rates for each ID for the leftward pointing movements are shown in Figure 3.4, the filled bars represent mean accuracy rate of the elderly group, while the open bar represent mean accuracy rate of the young group. The present study performed a task (four tasks) x ID (five levels) x age (two groups) repeated measures analysis of variance (ANOVA) on the mean accuracy rates, in which task and ID were used as within-subject factors and age as a between-subject factor. The present study found no significant main effects of age on the mean accuracy rate, $F(1, 28) = .074$, $p = .788$. However, the present study found significant main effects for ID, $F(4, 112) = 117.189$, $p < .001$; and task, $F(3, 84) = 86.112$, $p < .001$. Moreover, the present study found no significant interaction between age and ID, $F(4, 112) = 1.217$, $p = .308$; no significant interaction between age and task, $F(3, 84) = 1.353$, $p = .265$; and no significant interaction in age, task and ID, $F(12, 336) = .760$, $p = .598$. However, the present study found significant interaction between task and ID, $F(12, 336) = 14.562$, $p < .001$. Since there were no significant main effects of age on main accuracy rate, the present study performed task (four tasks) x ID (five levels) repeated measures analysis of variance (ANOVA) on the mean accuracy rates of all subjects. The present study found significant main effects of ID, $F(4, 116) = 116.317$, $p < .001$, and task, $F(3, 87)$

= 85.076, $p < .001$; the accuracy rates were lower for targets with higher ID values and for tasks involving less visual feedback (e.g., the NV task). The analysis also revealed a significant interaction between task and ID, $F(12, 348) = 14.684$, $p < .001$. A post-hoc comparison using the Bonferroni correction ($\alpha = .05$) found no significant differences in accuracy rates across the four tasks and for IDs of 1 ($p > .05$). The accuracy rates for the FV task were higher than the rates for NM task and NV task for IDs 3-5 ($p < .001$), and higher than the rates for NT task for IDs 4-5 ($p < .01$). Moreover, the accuracy rates for the NT task were higher than the rates for the NM task and for NV task IDs 3-5 ($p < .01$). However, the study found no significant differences in the accuracy rates under the NM and NV conditions for all IDs ($p > .1$).

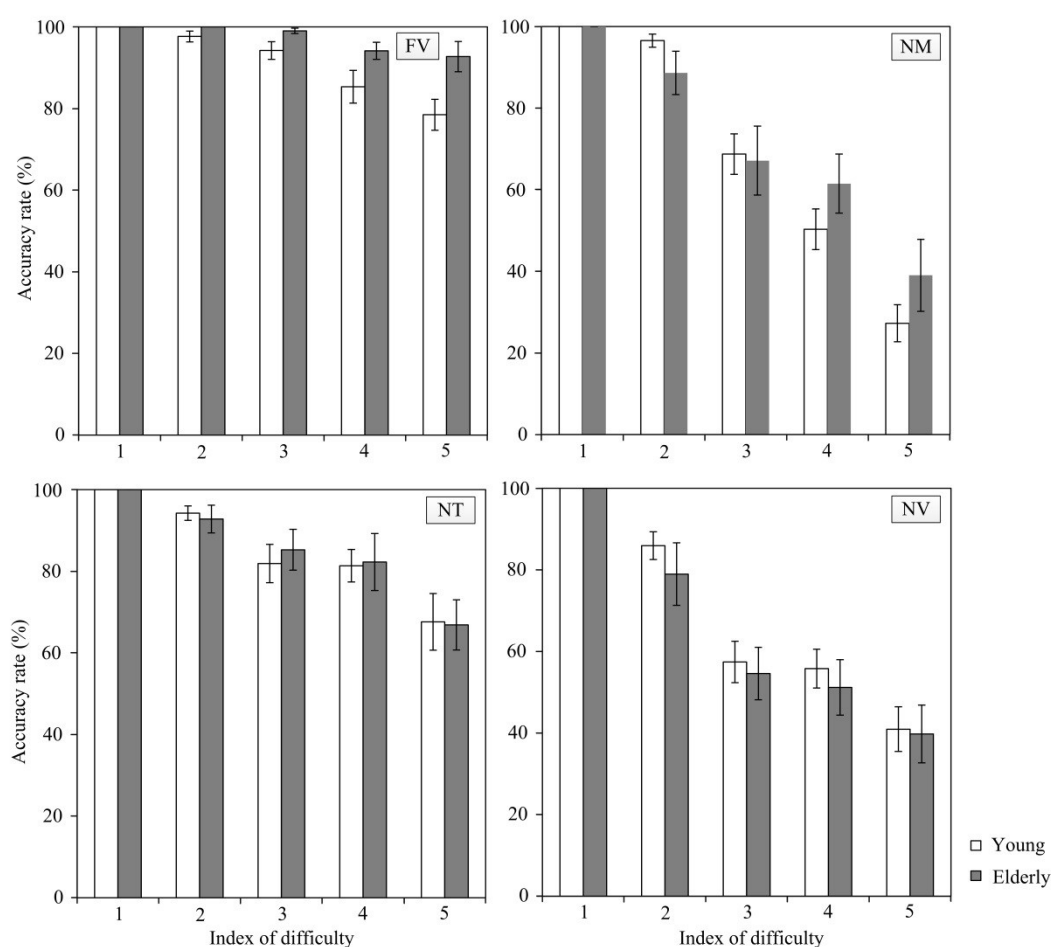


Figure 3.4 Mean accuracy rates for young group and elderly group as a function of the index of difficulty for all pointing tasks. The filled bars represent mean accuracy rate of the elderly group,

while the open bar represent mean accuracy rate of the young group. The error bars represent the standard errors of the mean (SEM).

3.3.2 Movement time

To investigate the effects of aging on the contribution of restricted visual feedback of the pointing movements, the present study also calculated the mean movement times (MTs) for the four pointing tasks of the two age groups (Fig 3.5). The study performed a task (four tasks) x ID (five levels) x age (two groups) repeated measures analysis of variance (ANOVA) on the mean MTs, in which task and ID were used as within-subject factors and age as a between-subject factor. The present study found significant main effects of age, $F(1, 28) = 13.596$, $p = .001$, task, $F(3, 84) = 12.515$, $p < .001$, and ID, $F(1, 112) = 267.730$, $p < .001$. Moreover, the present study also found significant interaction between age and task, $F(3, 84) = 4.05$, $p = .025$. However, the present study found no significant interaction between age and ID, $F(4, 112) = 1.747$, $p = .194$, and no significant interaction between ID and task, $F(12, 336) = 1.991$, $p = .146$. The present study also found no significant interaction within age, task and ID, $F(12, 336) = .458$, $p = .637$. A post-hoc comparison using the Bonferroni correction ($\alpha = .05$) revealed that the MTs of the elderly subjects were significant longer than the young subjects in the FV task for IDs =1-5, $p < .05$, in the NM task for IDs =1-5, $p < .01$, in the NT task for IDs =2-5, $p < .05$, and in the NV task for IDs =3-5, $p < .05$.

3.3.3 Linear relationship

As shown in Figure 3.5a–d, the present study has plotted the mean MTs of 15 young participants and 15 elderly participants against the IDs to test whether Fitts' law applies for pointing movements of both the young and elderly adults under the above mentioned four conditions.

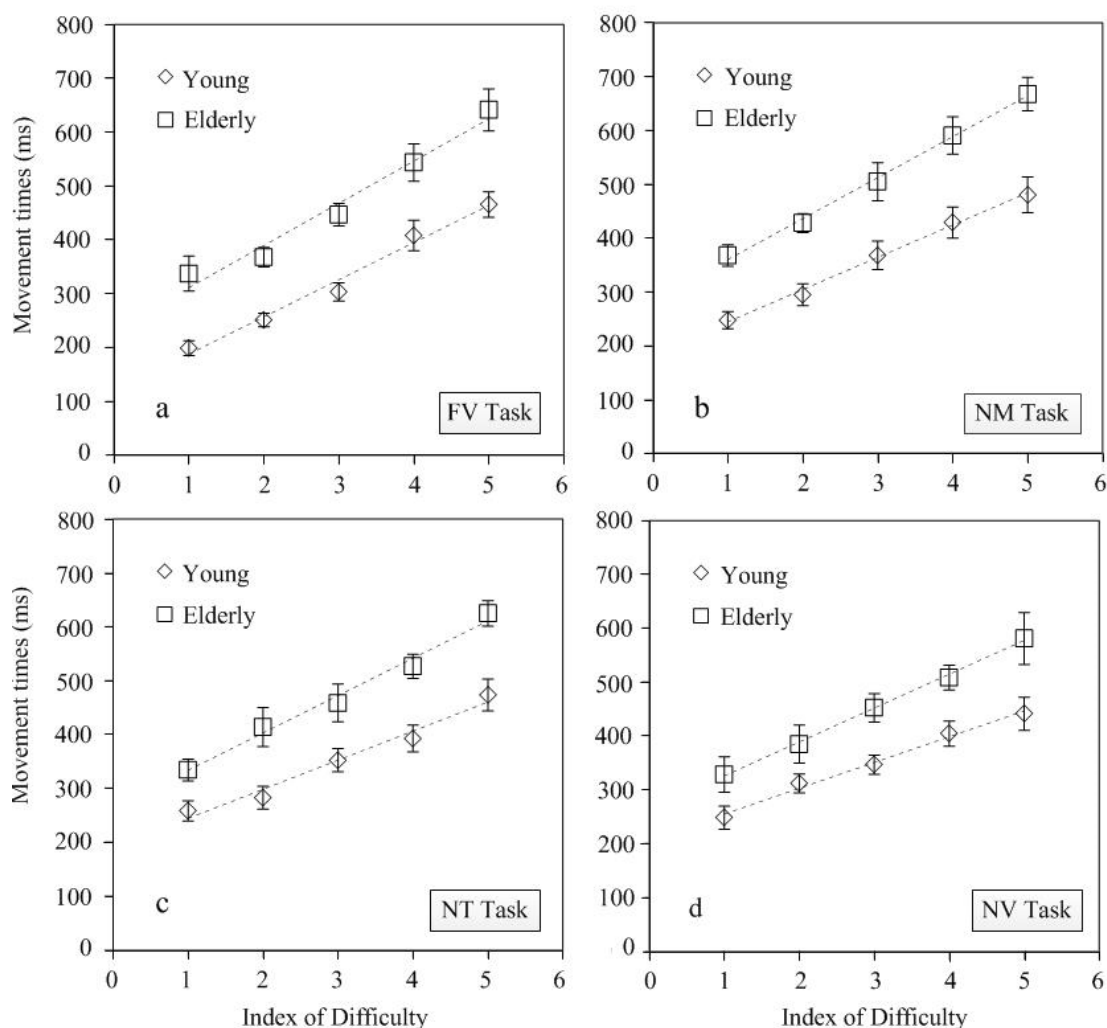


Figure 3.5 Mean movement times for the young and elderly groups as a function of the index of difficulty in the FV (a), NM (b), NT (c), and NV (d) tasks. Also shown are the corresponding linear regression lines (dashed). The error bars represent the standard errors of the mean. Significant main effects of age, task, and ID were found.

MTs of the two age groups all increased linearly as a function of the ID in the four visual restriction tasks. The regression analysis of the mean MTs of the young groups yielded significant r^2 values of .983, .996, .973, and .992 for the FV, NM, NT, and NV tasks, respectively (FV: $F(1, 3) = 169.265$, $p < .001$; NM: $F(1,3) = 715.953$, $p < .001$; NT: $F(1, 3) = 108.085$, $p < .01$; NV: $F(1, 3) = 352.552$, $p < .001$). The y-intercepts (i.e., a constants) and slope (i.e., b constants) coefficients in Fitts' equation for all four tasks were: FV task, $MT = 118.035 + 69.041ID$; NM task, $MT =$

183.535+ 60.021ID; NT task, MT = 189.064 + 54.051ID; and NV task, MT = 206.152 + 47.853ID. Moreover, the regression analysis of the mean MTs of the elderly groups yielded significant r^2 values of .970, .997, .985, and .998 for the FV, NM, NT, and NV tasks, respectively (FV: $F(1, 3) = 97.98$, $p < .01$; NM: $F(1,3) = 914.199$, $p < .001$; NT: $F(1, 3) = 200.233$, $p < .001$; NV: $F(1, 3) = 1608.942$, $p < .001$). The y-intercepts (i.e., a constants) and slope (i.e., b constants) coefficients in Fitts' equation for all four tasks were: FV task, MT = 231.819+ 78.44ID; NM task, MT = 282.717+ 76.254ID; NT task, MT = 262.623 + 69.487ID; and NV task, MT = 261.616+ 62.963ID.

3.4 Discussion

The current experiment examined the influence of aging on the pointing tasks, while varying the degree of restriction of the visual feedback by contrasting the pointing performances of the two age groups. The present results suggested that Fitts' law applied for the pointing movements of both the young and elderly adults under different visual restriction conditions. Moreover, there was a significant main effect of aging on movement times in all four tasks; the elderly subjects took a markedly longer time to complete their movements. However, no significant main effects of age on the mean accuracy rate condition of the restricted visual feedback were found.

3.4.1 Fitts' law

In the present study, the young and elderly subjects performed all of the tasks after taking 5 s to form visual memories of the target location and their hand position. The subjects were then asked to point to the target as quickly and as accurately as possible. Thus, all of the subjects were able to complete object cognition, movement planning, and perceptual feedback in all of the tasks before each trial started. Previous studies have also suggested that a 5-s waiting period did not affect the motor planning process in elderly adults [80]. Moreover, Rosenbaum et al [81] and Synofzik et al [82]

have suggested that the participants can execute self-action movement well under no vision condition when the information of target or hand position is memorized correctly. In addition, previous studies have also observed that participants also used proprioception and remembered information of target location to complete reaching movements [83,84]. Consistent with above mentioned findings, the subjects of the two age groups were able to perform the pointing movement under conditions of intact visual feedback (FV tasks, Figure 3.5a), restricted visual feedback (NM and NT tasks, Figure 3.5b and c) and no visual feedback (NV tasks, Figure 3.5 d). The pointing movements in these trials reflected typical goal-directed reaching movements (discrete pointing movements) that followed Fitts' law (Figure 3.5a). Consistent with the suggestion of Wu, et al [16], although the pointing movements were performed under conditions of monocular viewing in the present study, there were no significant divergences from Fitts' findings in terms of the linear relationship between MT and ID [8].

The y-intercept and slope of the regression line are two most important parameters for testing whether Fitts' law holds for visually guided pointing movement of the elderly under visually restricted conditions. Although the linear relationships between MT and the ID were extremely robust across all four tasks for both age groups (with correlations above .97), the y-intercept of the present study was positive and higher than that observed in the classical Fitts' task [8,54]. In the present study, the y-intercept values of the young group were positive and greater than 108 ms, while the y-intercept values of the elderly group were also positive and greater than 231 ms. As above mentioned in the introduction, since Fitts' equation was first proposed, the disagreement on the non-zero y-intercept has also been suggested by Fitts et al [54] and Soukoreff et al [55]. Fitts et al [54] has implied that the y-intercept should theoretically always be strictly positive. Some explanations of the positive

y-intercept and the higher y-intercept have been suggested in previous studies [16,53,55,85]. Fitts and Radford [53] have also interpreted the reason of the positive y-intercept as unavoidable delay in the psychomotor system. Moreover, MacKenzie [85] has attributed uncontrollable muscle activity at the start or end of the movement task to the positive y-intercept in Fitts' task. Furthermore, Wu et al. [16] also suggested that higher y-intercept value may results from the delay at the end of the discrete pointing movement. Thus the study suggested that the above mentioned three reasons may result in the positive and higher y-intercept value in the present results.

As above mentioned, the slope of the regression line is another important parameter in Fitts' law. Although the linear relationships between MT and the ID of the two age groups were extremely robust across all four tasks, the slope of the regression line in the present study is also different from it observed in the classical studies of the reciprocal pointing movement task. Consistent with the results of the young group, the slope of the regression line of the elderly group in the FV task was smaller than the slope in the classical Fitts' task [8,65]. The previous researches have also presented similar results that the value of the slope of the regression line in their discrete pointing tasks was smaller than that observed in the classical Fitts' task [16,57,58]. Thus, the value of the slope of the regression line of the two age groups was in agreement with the findings of the above mentioned studies. Moreover, value of the slope of the regression line of the two age groups in the NM, NT, and NV tasks were smaller than in the FV task respectively. Wu et al. [16] have suggested that the shorter MTs for the high IDs in the similar restricted visual feedback tasks contributed to the result. In sum, the present study suggested that Fitts' law applies for pointing movements of both the young and elderly adults under different visual restriction conditions.

3.4.2 The effects of aging on movement time

As expected, there was a significant main effect of aging on movement times in all four tasks; the elderly subjects took a markedly longer time to complete their movements. This slowness was not specific to the conditions of visual restriction (NM task, NT task and NV task) because the elderly subjects were significantly slower than the young subjects, even when executing pointing movements without visual restriction (FV task). The reasons for this slowing have been attributed to both peripheral and central changes [86]. On the one hand, peripheral changes occur in muscle spindles, which, in turn, may influence muscle contraction properties in elderly people [87]. As a result, these changes may cause the elderly people loss part of muscle strength and power, and slowed their peripheral motor and the sensory nerve conduction velocities [88-90]. On the other hand, aging causes deterioration of the dendrites in the motor cortex [91], visual motor cortex or other high level processing cortex, such as working memory [71,92,93] and decision making [94]. These degenerations slow down the cognitive processing of human. In conclusion, the peripheral and central changes may account for the slowness of elderly people in the pointing movement under different visual restriction conditions.

3.4.3 The effects of aging on accuracy

Although there was a significant main effect of aging on movement times, there were no significant main effects of aging on the mean accuracy rate under full visual feedback condition (FV task) and restricted visual feedback conditions (NT, NM and NV conditions). The present study suggested that the elderly subjects made a similar use of the available sensory information (vision and proprioception) as the young subjects. The accuracy rates of both young and elderly subjects were significantly lower in the restricted visual feedback tasks (NT, NM and NV tasks) than those in full visual feedback task (FV task). This suggested that regardless of the age group, the

combination of visual and proprioceptive afferent information is more efficient than under the control of visual or proprioceptive information alone. Under the NM conditions, visual feedback of hand's movement was absent. However, the target location was visible throughout the movement. The accuracy rates of the elderly and the young subjects was not significantly different is in agreement with the findings of Pelisson [51] and Sarlegna [72] that the elderly subjects are as capable as young subjects to monitor movement trajectory through refining target location continuously with visual information. While under the NT conditions, the target position prior to pointing movement can provide extraretinal target location information that can be used during the movement if the target disappeared. As above mentioned, the accuracy rates for the NT task were significantly lower than the accuracy rates for the FV task. However, the accuracy rates for the NT task were significantly higher than the accuracy rates for the NM and NV tasks. These results indicated that information about the hand's movement was more useful than the information about the target location for the movement accuracy rates of both young and elderly subjects in pointing movement. The elderly subjects are as capable as young subjects of retaining target location in memory and to adjust their hand movements appropriately to obtain higher accuracy rates compared to the NM and NV tasks, which supported the earlier findings of Haaland et al. [14] and Wu et al [16]. Under the NV conditions, both visual feedback of hand's movement and target location were absent. The accuracy of the elderly and young subjects was also not significantly different in the NV condition. Both the elderly subjects and the young subjects obtain lowest level accuracy. The present study suggested that the elderly subjects are as capable as young subjects of retaining target location in memory and making good use of internal representations in the context of arm movement control. Consistent with the demonstration of Brouwer et al [83,84] and Praat et al [95], the accuracy of the movements guided by

proprioception and memory was poorer than the accuracy of movements guided by visual information regarding the target or hand position.

3.5 Conclusions

In conclusion, there was a significant main effect of aging on movement times under restricted visual feedback of hand movement and target location. However, there were no significant main effects of aging on the mean accuracy rate. The elderly subjects made a very similar use of the available sensory information (vision and proprioception) as the young subjects. Moreover, Fitts' law applies for pointing movements of the elderly adults under different visual restriction conditions.

Chapter 4 Application of Pointing Movement on Human Computer Interaction Interface Design

Summary

The present study introduced a kind of miniature detecting robots with multi-mode deployment. The robots being provided with necessary sensors, can be deployed to the target areas by air, grenade launch and trigger mechanism or thrown by hand. The robots can detect and collect the vital information in the target areas through human-computer interaction (HCI) controlling and monitoring, which can provide the first hand information for decision-making. The efficiency of the human-computer interaction is an important aspect of the robots for achieving their rapid response. The present study presented the behavioral science theoretical base of HCI interface design for the elderly adults. Moreover, the theoretical base of behavioral science for designing universal human computer interaction interface was presented. Furthermore, the factors affect HCI interface design, including the target width, target attitude, target shape and angle of approach, were introduced and analyzed. At last, the universal HCI interface of the miniature detecting robots with multi-mode deployment was presented to raise the efficiency of human-computer interaction.

Keywords: Univesal human-computer interaction interface, Miniature detecting robots with multi-mode deployment, Pointing movement, Fitts' law, Movement time

4.1 Background

The high-risk domains or unknown areas, such as severe natural disasters, chemical pollution incidents, anti-terrorist scenes and battlefield goals, are usually hard to reached quickly due to the complexity of the situations. The miniature detecting robots with multi-mode deployment were well suited for above mentioned detection. The robots being provided with the necessary sensors can be thrown by hand or deployed to the target areas by air, trigger mechanism (Figure 4.1). The robots can detect and collect the necessary and vital information in the target areas through human-computer interaction (HCI) controlling and monitoring, which can provide the first hand information for decision-making [96-98].

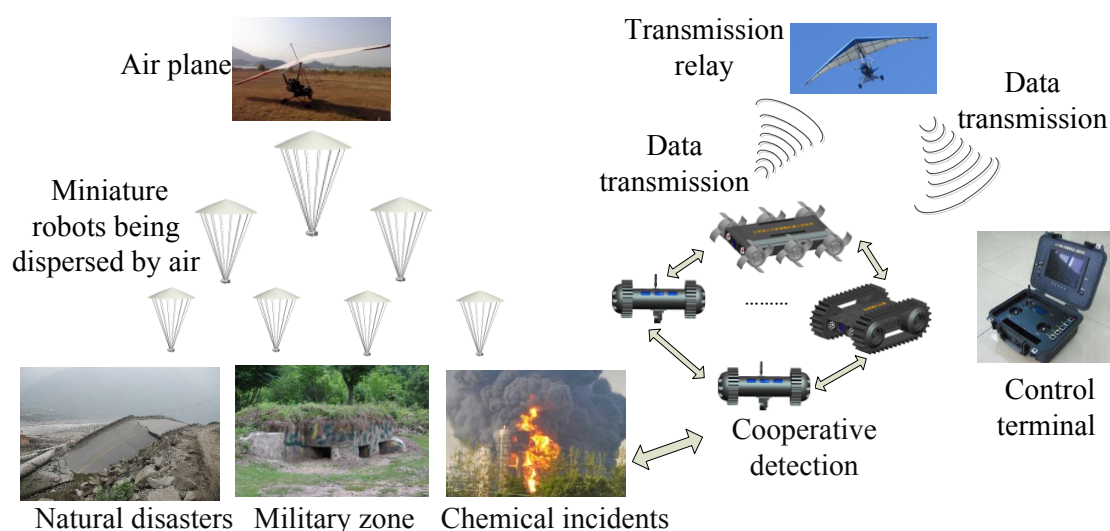


Figure 4.1 Rapid dispersing operation processes of multi-mode robotic detecting system

To deal with the close detection missions, such as city terrorism and street fighting, the robots can be thrown into the target area by hand. While for long-range detecting missions, such as detective disaster of earthquake, chemicals testing and military investigation, the robots can be deployed to the target areas by air or trigger mechanism [96-98]. As shown in Figure 4.1, this paper introduces the operation processes of the multi-mode robotic detecting system taking an air dispersing mode

for example [97]. The multi-mode robotic detecting system was mainly composed of rapid dispersing devices, soft-landing buffer mechanism, two-wheeled robots, four-wheeled robots, six-wheeled robots and network communication system. The air plane flied to the stricken area and acquired images by its Eagle Eye camera. Then, the images, superimposed OSD information and the altitude of aircraft would be transmitted to ground control station through image transmission system. Thus, the control center personnel would get the first perspective and decide the exact airdropped area by the human computer interactive information transmitted by aircraft. Moreover, the monitoring systems would acquire aircraft position signal by onboard GPS. According to MAVLINK communication protocol, the information would be transmitted to ground control station by image transmission system. The flying track display and planning would be achieved through analysis the positon of the aircraft. The control center personnel would select the airdrop area according the real time image. Furthermore, the rapid dispersing device attached on the airplane would airdrop the robots and their soft-landing buffer mechanism into the above mentioned selected area. And then, the parachute of the soft-landing buffer mechanism opened and dropped with soft-landing buffer mechanism slowly after being pushed out. The triggers of the soft-landing buffer mechanism would contact with the ground and open automatically as soon as they fall to the ground. Then the miniature detecting robot would be pushed out and carried out detecting mission. Through deployment a series of robots, the robots can obtain autonomous detection and cooperative detection. After the dispersing, the aircraft continued to hover in target area and acted as the communication relay between ground control station and the robots. Lastly, with high-power Wi-Fi transmitter, the system can continuously maintain extensive wireless LAN. Under the wireless LAN circumstances, the robots could collect and return the images, sounds and hazardous chemicals spectral information of the target

area through the relay in the airplane and on the ground.

According to demand of the operating environment, mission requirement and the control system architecture of the miniature detecting robot, the robots adopt control and monitoring system framework. In order to improve the adaptability and independence of the robots during information detecting in target area, the robot operating system design mixed with the remote operation mode and autonomous detecting mode. As a human robot interaction carrier, the control and monitoring system can accomplish real-time switch between remote operation mode and autonomous detecting mode, and real-time monitor the motion of the robot and working conditions of the sensor. As shown in Figure 4.2, the interaction interface of the control and monitoring system framework was composed of graphical interface feedback by robots, flight path vector visual interface, flying track display and the host human-computer interaction interface.

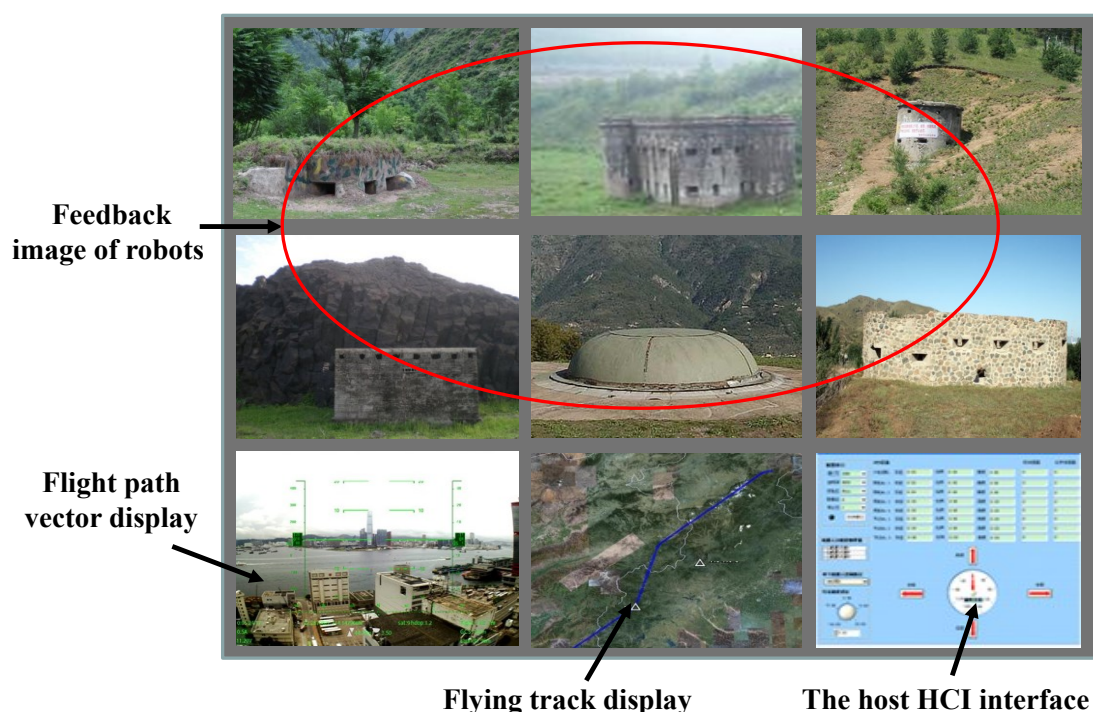


Figure 4.2 The interaction interface of control and monitoring system framework

The efficiency of the human-computer interaction is an important aspect of the

robots for achieving their rapid response. User accomplished interaction with robots mainly through operating the HCI interface. Thus, it is necessary to study the design method of HCI interface. In addition, the miniature detecting robots not only can be used in disaster areas inspecting, chemicals testing and military investigation, but also can be used in intelligent teaching and displaying in the science and technology museum. The operation of the robot needs to meet the demand of different user groups, including the factor of age, gender, race, cultural background, and so on. Thus, both similarities and differences of users should be taken into consider for designing universal or differential HCI interface to raise the efficiency of human-computer interaction.

4.2 Theory foundation of HCI interface design

Users were mainly through operating the human-robot interaction interface to control and monitor robots. Thus, the human-robot interaction process is virtual the interaction between human and computer. As shown in Figure 4.3, user carried out an input operation through mouse or touch pen to computer. Then the information input would be processed and stored in the computer, and finally presented to the user via display devices. The graphics information displayed by output device is formed visual information by human visual perception system. After processing by visual cortex, the visual information would be divided into spatial information, time information and other type of information, such as color, shape and level. After being screened through top-down attention mechanisms, the inner part of sensible business matching information is further processed to form a human short-term memory and long-term memory. Through co-processing of association cortex and motor cortex, the kinesthetic perception would be formed. And then human can carry out input operation and interaction with computer. The processing of the human-computer

interaction is virtual a processing procedure of visual and tactile information by human brain during pointing movement under visual feedback conditions. Thus, pointing movement was the behavioral science theoretical base of human computer interaction interface design.

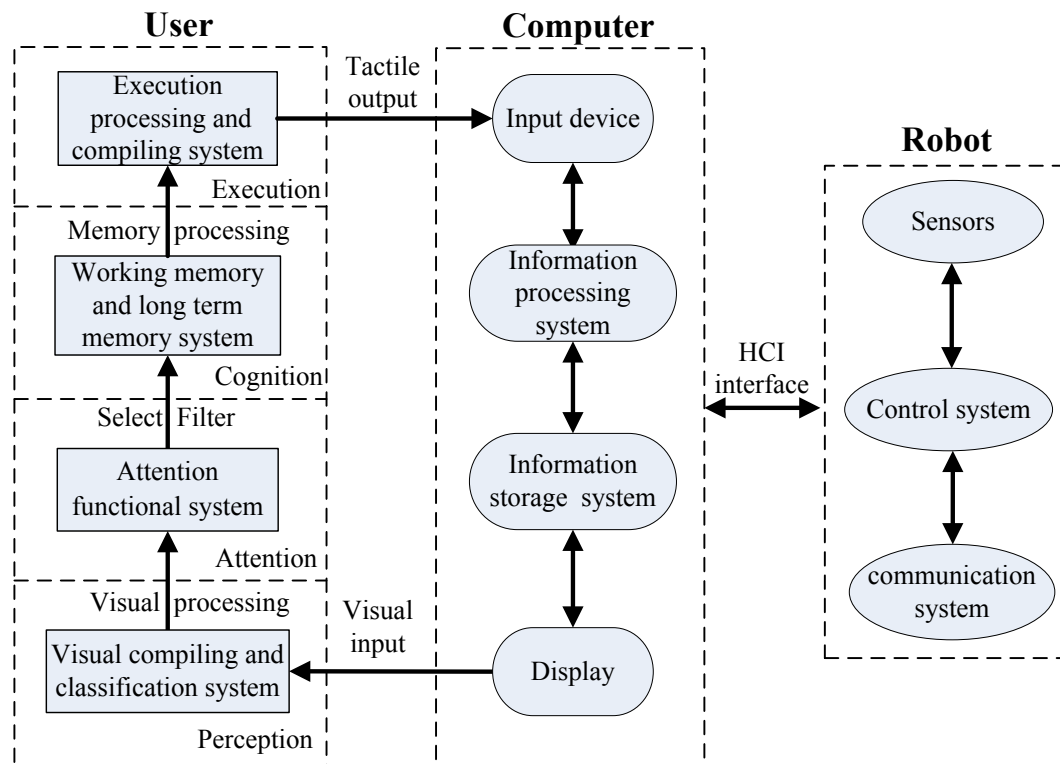


Figure 4.3 Pointing movement information processing mechanism during human computer interaction

The movement time and accuracy rate of pointing movements associated with computer input devices have often been modeled by Fitts' law. Since Fitts' law firstly confirmed the applicability of rapid-movement, the relationship between the MT and ID has been confirmed to hold for rotational movements, prehension movement, and foot movements, except for imagined pointing movements [59-65]. Moreover, Fitts' relationship has been replicated hundreds of times across a wide range of conditions, including pointing at two-dimensional, three-dimensional targets, obstacle avoidance tasks and so on. Recently, Fitts' law has proven increasingly useful in

human-computer interaction (HCI) study by providing a model to account for the movement time of a user's successful movement to capture a target with a direct manipulation device, such as a mouse or touch screen [99-102].

In experiment 2 (chapter 3), the study has suggested that Fitts' law applies for pointing movements of the elderly adults and the young adults under different visual restriction conditions. The previous studies have suggested that Fitts' law holds for pointing movements of the young adults with or without restricted visual feedback conditions. It is the behavioral science theoretical base of HCI interface design for the young adults [8,14-16,55]. The present study presented the behavioral science theoretical base of HCI interface design for the elderly adults. Thus, the Fitts' law can be used for designing the HCI interface which suit for the elderly using.

Moreover, the present study found there were no significant main effects of age on the mean accuracy rate under condition of restricted visual feedback. The study suggested that the elderly subjects made a very similar use of the available sensory information as young subjects under restricted visual feedback conditions. However, there were significant main effect of aging on movement times has been found in all tasks; the elderly subjects took a markedly longer time to complete their movements. The present study suggested that the peripheral and central changes may account for the slowness of elderly people in the pointing movement under different visual restriction conditions. It is impossible to control for such differences of movement time between the young and the elderly, whatever HCI interface might be designed. Thus, the present study suggested that the HCI interface design might not need to excessively take the age difference into consider. A Universal HCI interface might be more appropriate than a differential one.

In addition, on the one hand, significant main effects of the ID and task on movement time of both the young and the elderly groups were found. Movement time

of the young and the elderly were longer for more difficult (greater ID) targets and for tasks with more visual feedback. On the other hand, significant main effects of ID and task on the accuracy rates of the two groups were found. The accuracy rates of both the young and the elderly were lower for targets with higher ID values. Amplitude of pointing movement and target width are two variables used to compute the ID for Fitts' law. Logically, longer amplitude requires more precise movements and should, therefore, take longer to select than shorter distance, which is the finding in both the present study and the previous studies. Thus, research related to various aspects of movement time and accuracy of pointing movement has become increasingly important to the design and implementation of effective human-computer interaction interface. The study will discuss and study the influential factors of movement time and accuracy, and then form universal design methods of human computer interaction interface of miniature detecting robots with multi-mode deployment to raise the efficiency of human-computer interaction.

4.2.1 The factor of target width and amplitude

It is well known that Fitts' law predicts the duration of a movement to a target based on the size of the target and the distance from a starting position to the target [8]. The effectiveness of Fitts' law in accounting for MT, however, is influenced by target size and the distance to the target from a starting position. Amplitude of mouse movement and target width are two variables used to compute the ID for Fitts' law. Logically, longer amplitude requires more precise movements and should, therefore, take longer to select than shorter distance, which is the finding in both the present study and the previous studies. And similarly, smaller targets require more precise movements and take longer to select than larger ones. The residuals analysis, however, showed that Fitts' law was a better predictor of movement time at the shortest amplitude and largest target sizes. This effect might be partially owing to the manner

in which subjects moved the cursor in relationship to different amplitudes and target widths.

Gillan and Neary [103] have reported that pointing time showed orderly increases in mouse MT to a text object as distance increased for eight different horizontal sizes of text objects in examining pointing in a text-editing task. Moreover, Whisenand and Emurian [104] have investigated the interactive effects on movement time of the size of the target and the distance to the target for the use of a mouse to select icon-like targets presented on a computer's display screen. They found that target width and the amplitude significantly affected mouse movement time. They suggested that arranging target-type icons or buttons with a size 0.5 to 1.5 cm², at a distance of 40 mm or less on the monitor would be anticipated to improve the performance of target selection with a mouse, where control of accuracy and mouse movement time are issues of common concern with targets that are dynamically displayed. Recently, Whisenand and his partner [101] have researched the cursor movements with a mouse input device under conditions of variations in the angle of approach to the target, the target size and shape, the distance to the target, and the nature of the task, drag-drop or point-click. Though analysis of cursor movements, they have recommended that size the target objects between 8 and 16 mm in width and locate the target objects at a distance of 40 mm or less from the starting position. According the above mentioned studies, the target objects with width of 15mm and locate the target objects at a distance of 40 mm or less would be the preferred button for designing the human computer interaction interface of present study.

4.2.2 The choice of the target shape

The target shape of the human computer interaction interface is an important factor for HCI design. The importance of considering target shape is related to its impact on the determination of the effective width of a target. The previous studies

have investigated the effect of the target shape in a Fitts movement task [99,101]. Sheikh and his collaborators have investigated the movement time (MT) vs index of difficulty (ID) relationship for the target that were triangular, square, circular and diamond in shape. The diamond and equilateral triangle were found to be the most difficult shapes, in that they took a longer time to perform a movement for given target width [99]. Moreover, Whisenand et al [101] have examines the effects on MT of the angle of approach, amplitude of movement, and target width for Fitts' tasks in the selection of square and circular objects displayed on a computer screen. They found that target shape had a significant effect on MT for the pointing movement. MTs for square targets were significantly shorter than for circle targets. According the above mentioned results, the square target would be the preferred button for designing the human computer interaction interface.

4.2.3 The factor of angle of approach

The distribution of the button of the human computer interaction interface is also an important factor for HCI design. Boritz et al [105] have designed experiments to test the hypothesis that there was a relationship between the direction of motion (angle) and the time required to move the mouse tracker to a target. They found more rapid mouse-driven cursor movements at 0°, in comparison to 270° for item selection in a “pie-shaped menu” that consisted of icon-like square targets. MacKenzie and Buxton [106] have also reported that the longer movement time for targets at 45° in comparison to targets at 0°; they contrast with the latter results, however, by finding that movements at 90° took longer than at 45° in goal-directed movement experiments. Moreover, Whisenand and Emurian [100] have investigated the interactive effects on movement time of the angle of approach, the size of the target, and the distance to the target for the use of a mouse to select icon-like targets presented on a monitor. They found that angle of approach, target size, and target distance significantly affected

movement time. The movement times were significantly shorter along the horizontal directions (0° or 180°) in comparison to movements along the vertical directions (90° or 270°). The findings above mentioned should improve the design of human computer interaction interface, and they may be of value to researchers and practitioners interested in applying a Fitts' law model to target acquisition tasks in a computer's display screen. Thus, the angle of approach of human computer interaction interface of the present study should be studied carefully. According the results above mentioned, the present study should approach the target objects from an angle of 0° or 180° for designing the human computer interaction interface.

Besides the above mentioned factor for HCI interface design, and the target importance principle are also very important points to be evaluated for the HCI interface design [55,107-110]. Frequency principle, that is, to design the hierarchical order and the display position of the dialog box of the HCI interface in accordance with the using frequency of the pointing objects [109,110]. It can effectively improve the monitoring level and accessing frequency. Indeed, a target's total displacement is proportional to its attitude. Likewise, the total movement time is also approximately proportional to its attitude. On this account, the more frequently using target should be distributed closer to the starting point of the pointing movement than the less frequently using one and vice versa. That distribution can effectively reduce pointing movement and effectively increase the human computer interaction efficiency. The target importance principle is to distribute the primary and secondary interface menus and dialog windows in accordance with the importance and global levels of the target in the HCI control system [107-110]. It may make the menus and dialog windows of interface more salience, and help user better grasp the primary and secondary relations about the different pointing target of the interface. The target importance principle is achieved when there is a clear viewing order to the visual elements on a screen. That

is, when users view the same items in the same order every time. Thus, the frequency principle and the target importance principle should be considered for the HCI interface design.

4.3 HCI interface design for miniature detecting robots

In the following passage, the present study would mainly carry out the optimal design of the HCI interface of the miniature detecting robots which was showed in the Figure 4.2.

The flight path vector visual image and flying track display are two important display interfaces during the airplane flying to the target area and dispersing the robots. Moreover, when the robots entered into the target area, the feedback images of each robot should be displayed real time in case of images omission. According the importance of the flying track display, flight path vector visual image and the feedback images of each robot, the most important image could be switched from auxiliary display to the larger main interface display at any time for better observing and detecting. Thus, as shown in Figure 4.4, the whole display interface design mixed with the main display interface and eight auxiliary interfaces, including the flying track display, flight path vector visual image display and the feedback images of each robot. The eight auxiliary display interfaces were distributed symmetrically on each side of the main display interface. The upper two auxiliary screen interfaces on both sides were the flying track display interface (marked as FT) and flight vector path display (marked as FV). These two parts also can be switched from auxiliary display to the larger main interface display at any time (Figure 4.5). Then, the six auxiliary interfaces are the feedback images of the miniature detecting robots, including two-wheeled robots (marked as R1 and R2), two four-wheeled robots (marked as R3 and R4) and two six-wheeled robots (marked as R5 and R6). They are distributed

symmetrically under the flying track display interface and flight vector path display on each side of the main display interface. Each of them also can be switched to show on the main interface at any time if necessary (Figure 4.6). The hierarchically distribution could effectively increase the fast-recognition capability of images and reduce short-term memory load.

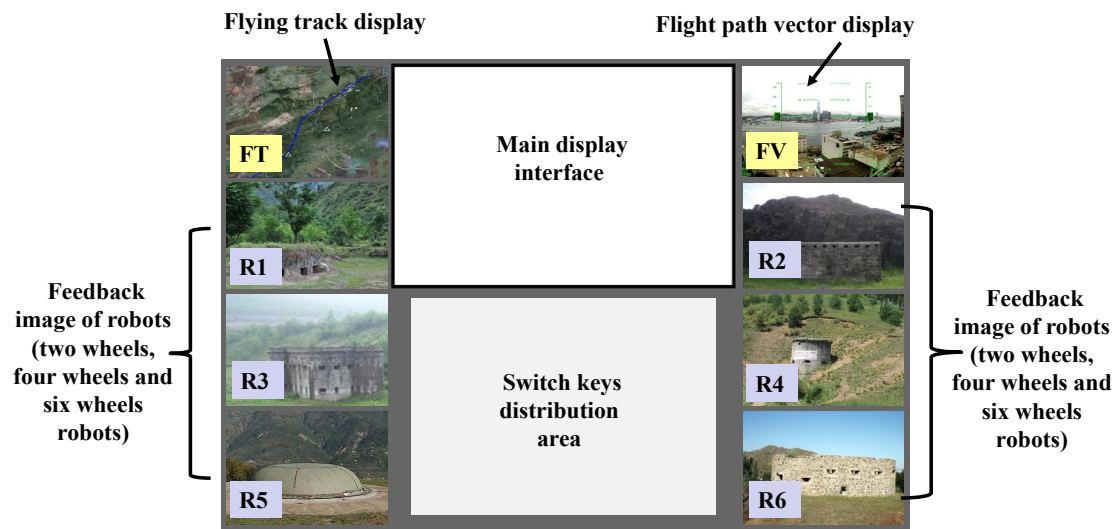


Figure 4.4 Layout of the visual display interface

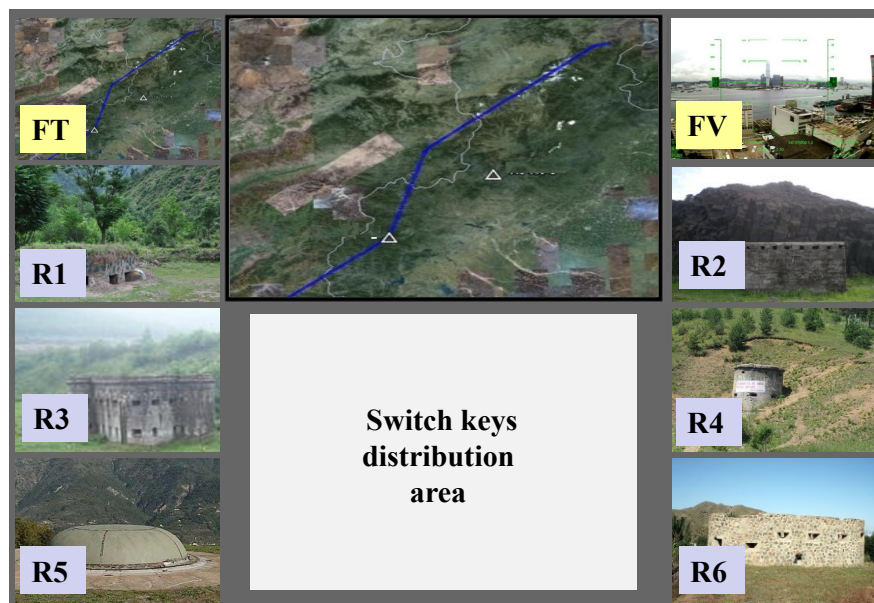


Figure 4.5 Layout of the visual display interface. The flying track display interface and flight vector path display can be switched to the main display interface at any time.

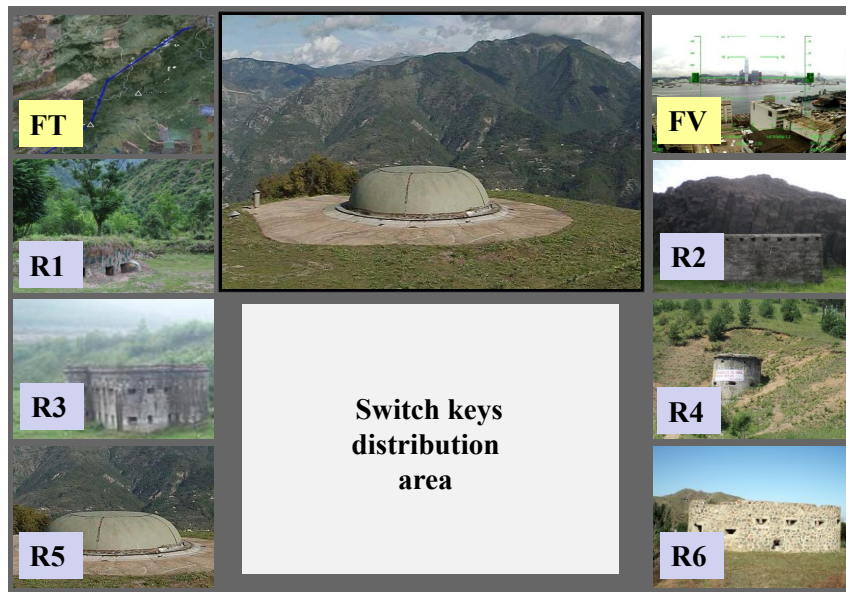


Figure 4.6 Layout of the visual display interface. Each of the feedback images of the robots can be switched to the main display interface at any time.

After introducing the distribution of the display interface, the switch keys of the motion control keys of the robots and eight auxiliary display interfaces switch keys should be consider every possible angle. After entering the target area, the robots would be operated by user through HCI interfaces in the remote operation mode. User could operate the robots to accomplish the basic movements, including forward, backward, turn left and turn right. Thus, the robot motion control interface should set up motion control keys, including “forward” switch key, “backward” switch key, “turn left” switch key and “turn right” switch key. Moreover, as mentioned in the former passage, the robot operating system design mixed with the remote operation mode and autonomous detecting mode. Thus, the robot motion control interface should set up the autonomous switch key to accomplish the bi-directional switch between the remote operation mode and autonomous detecting mode. User could switch the remote operation mode to the autonomous detecting mode to accomplish the autonomous detecting. During this mode, the robots could obtain autonomous detection and cooperative detection. User could also though pressing switch keys to

switch the autonomous detecting mode to the remote operation mode. In sum, the present HCI interface should include an autonomous detecting mode switch key, four motion control keys and eight display switch keys. Then, the present study will analyze the using frequency and the importance of the 13 keys above mentioned. The distribution of the above mentioned switch keys are main according to the frequency principle, the target importance principle, the factor of target width and amplitude, the choice of the target shape and the factor of angle of approach.

The “autonomous detecting mode” key was the switch key to switch the remote operation mode to the autonomous detecting mode or switch the autonomous detecting mode to the remote operation mode. Thus, it was the most frequent and most important key for users. In contrast with the “autonomous detecting mode” key, the four motion control key, including “forward”, “backward”, “turn left” and “turn right”, took the second place in terms of using frequency and importance. Moreover, the “forward” and “backward” switch keys were more frequently used by users than the “turn left” and “turn right” switch keys. The “forward” switch key was the most frequent keys among those four keys. Thus, on the basis of the target importance principle and using frequency principle, the “autonomous detecting mode” key was took as the pointing start and placed in center of the motion control interface. Then the four motion functional keys, including “forward”, “backward”, “turn left” and “turn right” were placed in a circle around the “autonomous detecting mode” key and circumferentially distributed placed in the inner layer in according of the using frequency principle. Due to the “forward” and “backward” functional keys were more frequently used by users than the “turn left” and “turn right” functional keys, thus the “forward” key and “backward” key were placed from an angle of 0 ° or 180° according to the factor of angle of approach. And then, the present study approached the “turn left” and “turn right” from an angle of 90° or 270°. The radius of this circle

was labeled as r_1 . The distribution of the motion switch keys were showed in Figure 4.7.

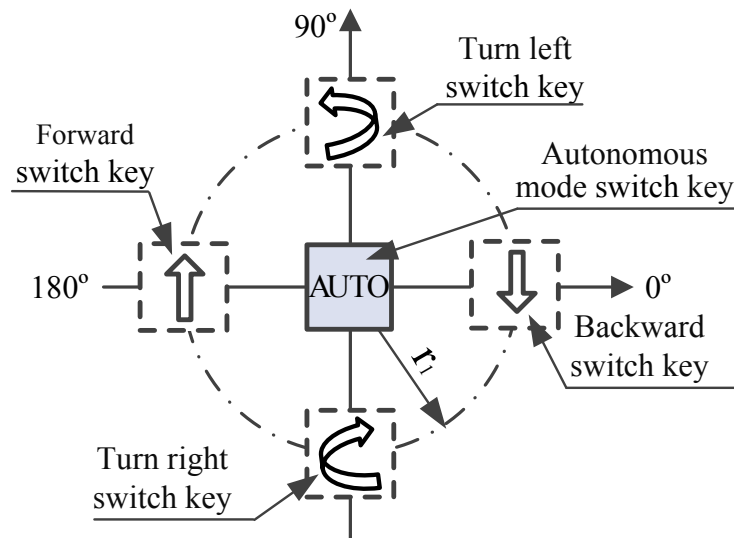


Figure 4.7 Distribution of the motion control keys

In contrast with “autonomous detecting mode” key and the four motion functional keys, eight auxiliary interfaces switch keys took the third place in terms of using frequency and importance. Thus, their switch keys were also placed in a circle around the “autonomous detecting mode” key and circumferentially distributed placed in the outer layer in term of the using frequency principle. The radius of this circle was marked as r_2 . Due to no clear distinction among the eight auxiliary interfaces switch keys in terms of using frequency and importance, the approach angle of the flying track display switch key was designed about 22.5° from Y-axis direction (90°). Then the other seven display switch keys, including the display switch key of robot 1-6, the flight path vector visual image and flying track display, were evenly distributed in a circle around the “autonomous detecting mode” key. As shown in Figure 4.8, the FT and FV each separately represent the display switch key of flying track image and the flight path vector visual image. R1 and R2 each separately represent the display switch key of two-wheeled robot 1 and robot 2, while R3 and R4

each separately represent the display switch key of the two four-wheeled robots, which listed as 3 and 4. Moreover, R5 and R6 each separately represent the display switch key of the two six-wheeled robots, which listed as 5 and 6.

This distribution would tend to smooth differences of the eight display switch keys during the using procedure. Moreover, the distribution of the display switch key of robots, flight path vector visual image switch key and flying track image switch key were correspond to the distribution of the six auxiliary screen interfaces of robot feedback images, auxiliary screen interfaces of the flight path vector visual image and flying track display. This distribution design could effectively increase the fast-recognition capability of images and reduce short-term memory load.

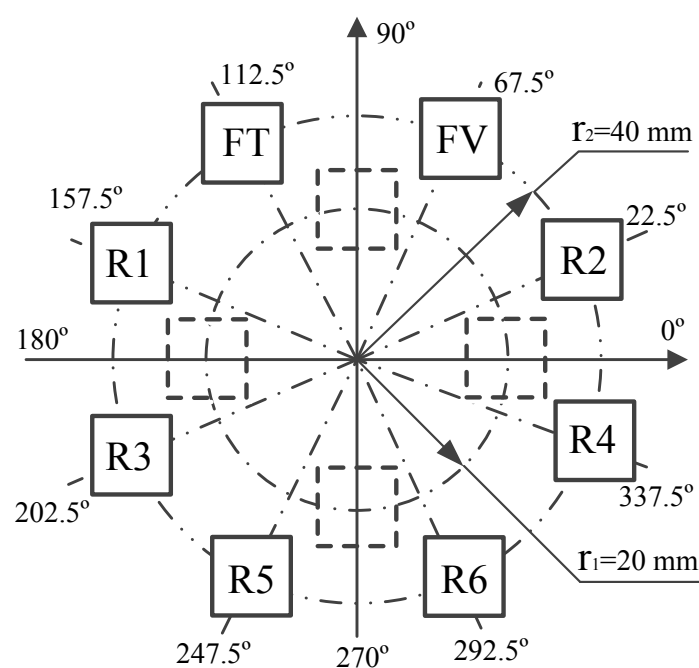


Figure 4.8 Distribution of the eight auxiliary interfaces switch keys

As mentioned in the chapter 4.2.2, the previous study found that movement time for square targets in the similar pointing movement were significantly shorter than the target shape of circle, triangular and diamond. Then, the square target would be the preferred key for designing the human computer interaction interface. As suggested, the square is chosen for HCI interface target shape of the present study. Moreover, the

target object with width of 15mm is chosen for HCI interface target width of the present study according the recommendation of the previous studies. This selection is not only suit for the cursor movements, but also fit for the pointing movement of touch screen. Furthermore, locating the target objects at a distance of 40 mm or less from the starting position would be the preferred button for designing the human computer interaction interface according the above mentioned studies. As suggested, the r_1 and r_2 were taken as 20mm and 40mm respectively in term of the factor of target amplitude (Figure 4.8).

In summary, the universal human-computer interaction interface of the miniature detecting robots with multi-mode deployment was presented in Figure 4.9. During frequent pointing movement, the present distribution could effectively decrease the amplitude the pointing movement and the movement time, thereby might effectively improve the convenience and efficiency of interaction human-computer interaction of both the young and the elderly.

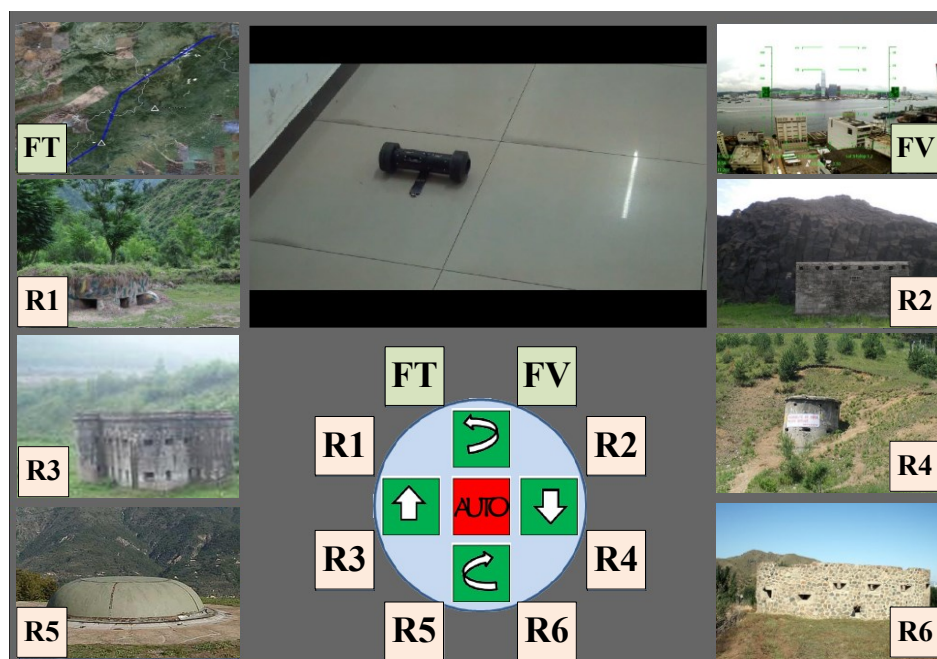


Figure 4.9 Universal human-computer interaction interface of the robots

4.4 Conclusion

The present study introduced a kind of miniature robots with multi-mode deployment for long-range detecting missions. The efficiency of the human-computer interaction (HCI) is an important aspect of the robots for achieving their rapid response. The present study presented the behavioral science theoretical base of HCI interface design for the elderly adults. Moreover, the theoretical base of behavioral science for designing universal human computer interaction interface was presented. Based on the behavior theoretical base, the design methods of human computer interaction interface of miniature detecting robots with multi-mode deployment have been introduced to raise the efficiency of human-computer interaction.

Chapter 5 General Conclusion and Future Challenges

Summary

This dissertation has investigated the influence of visual information on tactile and kinesthetic perception. In particular, the influence of aging on pointing movements under restricted visual feedback conditions and speed matching interaction between visual and tactile motion were discussed. Moreover, a universal human computer interaction interface design method of miniature detecting robots with multi-mode deployment has been presented which based on pointing movements. The findings are summarized below. In addition, the present study describes challenges for future research.

5.1 General conclusions

The dissertation is composed of 2 experiments and an application design. The first experiment investigates the effects of aging on pointing movements under restricted visual feedback of hand movement and target location. The second experiment explores the speed discrimination interaction between visual and tactile motion with unimodal tasks and crossmodal tasks. Moreover, the application of pointing movements was mainly researches the human computer interaction interface method of miniature detecting robots with multi-mode deployment.

Chapter 2 describes the second experiment, in which the unimodal tasks and crossmodal tasks were used to investigate the speed discrimination interaction between visual and tactile motion. The present study showed that both visual discrimination speed and tactile visual discrimination are underestimated relative to the standard speed at relatively high speeds in the unimodal task. The present study suggested that speed matching is processed similarly in both the visual and tactile sensory systems. Moreover, the present study demonstrated reciprocal interactions between the processing of visual speed matching and tactile speed matching. Visual speed stimuli positively affected tactile speed matching, while tactile speed stimuli disrupted visual speed matching at relatively high speeds. More interesting, visual speed stimuli can calibrate the tactile speed discrimination, but not vice-versa. The possible explanations is that the perceptual system is organized so that speed stimuli input from visual modality will receive a higher weighting in the interaction process than speed stimuli input from tactile modality. The reciprocal interactions between visual and tactile speed matching modalities directly supported the view that at some point in the motion processing streams, these two modalities have partially overlapping substrates.

Chapter 3 describes the first experiment, which investigate the effects of aging on pointing movements under different visual feedback conditions that included full visual feedback of hand movement and target location (FV), no visual feedback of hand movement and target location condition (NV), no visual feedback of hand movement (NM) and no visual feedback of target location (NT). This study suggested that Fitts' law applied for pointing movements of the elderly adults under different visual restriction conditions. Moreover, significant main effect of aging on movement times has been found in all four tasks. The peripheral and central changes may be the key factors for these different characteristics. Furthermore, no significant main effects of age on the mean accuracy rate under condition of restricted visual feedback were found. The present study suggested that the elderly subjects made a very similar use of the available sensory information as young subjects under restricted visual feedback conditions. In addition, during the pointing movement, information about the hand's movement was more useful than information about the target location for young and elderly subjects.

Chapter 4 introduced a kind of miniature detecting robots with multi-mode deployment. The robots being provided with the necessary sensor, can be deployed to the target areas by air, grenade launch and trigger mechanism or throwed by hand. The robots can detect and collect the necessary and vital information in the target areas through human-computer interaction controlling and monitoring, which can provide the first hand information for decision-making. The efficiency of the human-computer interaction (HCI) is an important aspect of the robots for achieving their rapid response. Pointing movement was the behavioral science theoretical base of human computer interaction interface design. Then the theoretical base of behavioral science and related factors for designing human computer interaction interface were introduced and analyzed. Based on the behavior theoretical base, the human-computer

interaction interface of the miniature detecting robots with multi-mode deployment was presented to raise the efficiency of human-computer interaction.

5.2 Future challenges

The present findings of the speed matching interactions between visual and tactile motion could have important implications for researching bionic hand-eye coordination algorithm of intelligent robot. Visual speed stimuli can calibrate the tactile speed discrimination, but not vice-versa. Such an influence can be taken into account in designing multimodal control system, such as might be found in visual and tactile coordination of humanoid robot.

The future work will focus on the basic theory of bionic visual and tactile coordination control algorithm for humanoid robot controlling. The key issues lie in researching the brain representation theory of speed matching interaction between visual and tactile motion; establishing the models of visual-tactile speed matching brain representation; forming the simulated human thinking and visual-tactile kinematic coordination fuzzy mathematics model. Using the new types of sensing materials and sensors with interactive think-touch fuzzy mathematical model, the future work will realize the effective performance of humanoid robot bionic visual-tactile coordination control real time with the integration of brain science and robot control strategy, which consists of memory, operation, comparative, identification, judgment, and decision-making concepts and methods. The solutions of these issues could improve humanoid robot's robustness in the complex environment and lay the foundation for the application of humanoid robot.

Appendix

I Individual behavior data of experiment 1

Table A I -1. Matching Speed of Subject 1 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	20.20	41.03	57.20	73.62	91.00	105.21
T-V Task	19.74	31.09	54.82	77.47	79.43	87.19
V-T Task	18.22	44.40	58.61	70.60	103.63	117.03
V-V Task	23.58	45.33	55.31	69.21	89.28	100.53

Table A I -2. Matching Speed of Subject 2 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	20.43	41.20	53.81	74.42	96.60	112.41
T-V Task	21.18	39.20	54.01	61.67	83.02	68.42
V-T Task	20.00	41.81	52.03	68.20	99.41	116.21
V-V Task	20.25	43.41	51.49	71.68	100.18	106.58

SS: Standard stimulus speed; **MS:** Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -3. Matching Speed of Subject 3 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	16.80	39.40	59.60	68.60	77.80	87.40
T-V Task	20.94	35.41	55.80	64.40	78.85	100.02
V-T Task	19.60	35.21	53.80	70.42	102.41	120.40
V-V Task	24.56	36.37	58.04	66.55	91.12	105.17

Table A I -4. Matching Speed of Subject 4 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	22.20	39.41	57.40	77.20	95.60	117.82
T-V Task	21.05	38.72	59.13	72.02	89.58	117.77
V-T Task	29.00	42.82	60.02	77.21	96.20	115.00
V-V Task	21.36	42.81	57.76	73.31	88.19	103.90

SS: Standard stimulus speed;

MS: Matching speed;

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -5. Matching Speed of Subject 5 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	24.40	46.01	55.80	77.42	97.20	125.75
T-V Task	17.44	44.69	59.24	72.80	83.65	87.20
V-T Task	25.01	48.00	51.42	77.40	112.44	127.40
V-V Task	22.49	37.04	54.83	66.66	110.07	101.34

Table A I -6. Matching Speed of Subject 6 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	21.80	44.20	58.80	77.60	92.20	113.60
T-V Task	22.26	37.60	67.87	72.73	101.50	130.30
V-T Task	25.80	44.80	58.21	80.62	99.60	123.80
V-V Task	21.98	41.42	61.12	71.16	101.77	105.90

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -7. Matching Speed of Subject 7 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	20.80	48.80	64.60	82.41	104.40	118.02
T-V Task	25.63	43.58	56.30	66.51	75.78	94.23
V-T Task	20.03	43.00	56.89	90.44	118.81	137.00
V-V Task	22.99	40.32	56.10	74.67	99.86	114.57

Table A I -8. Matching Speed of Subject 8 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	30.20	45.00	61.21	74.22	93.40	108.01
T-V Task	26.14	45.13	53.74	60.52	83.24	89.64
V-T Task	30.80	51.20	68.00	79.33	101.61	108.20
V-V Task	23.41	38.44	56.47	71.98	91.07	116.28

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -9. Matching Speed of Subject 9 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	25.40	42.40	56.21	70.40	92.82	109.00
T-V Task	19.77	32.80	50.35	58.20	72.08	86.03
V-T Task	43.60	56.62	59.80	76.81	92.20	110.80
V-V Task	22.49	38.50	55.22	75.68	108.95	117.12

Table A I -10. Matching Speed of Subject 10 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	30.60	44.00	60.81	82.01	95.21	119.42
T-V Task	17.73	29.21	42.30	50.83	62.39	78.61
V-T Task	27.40	47.82	67.00	86.41	120.20	140.80
V-V Task	21.38	40.46	50.80	70.33	101.53	99.85

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -11. Matching Speed of Subject 11 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	21.80	39.40	57.01	74.00	88.81	110.60
T-V Task	18.33	28.39	42.57	51.76	70.78	87.05
V-T Task	28.40	44.00	63.40	78.60	103.80	121.40
V-V Task	20.64	39.39	61.57	70.25	88.73	103.38

Table A I -12. Matching Speed of Subject 12 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	23.60	41.00	58.80	69.40	89.56	98.22
T-V Task	19.83	38.23	50.37	78.00	77.23	83.19
V-T Task	33.00	44.40	53.80	71.80	101.78	126.40
V-V Task	22.03	40.79	57.917	67.97	95.51	99.46

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -13. Matching Speed of Subject 13 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	34.40	45.20	63.40	80.40	91.60	96.20
T-V Task	21.47	37.77	62.81	68.06	63.81	100.01
V-T Task	31.20	47.20	62.20	79.60	102.80	112.80
V-V Task	22.54	41.85	62.52	76.75	104.49	106.47

Table A I -14. Matching Speed of Subject 14 in the Four Tasks (mm/s)

Task \ SS	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	22.20	43.00	60.60	80.20	100.00	121.00
T-V Task	21.83	36.61	48.64	62.19	76.76	101.62
V-T Task	22.60	40.00	54.00	76.00	103.40	120.20
V-V Task	20.82	39.48	53.27	75.36	97.78	105.16

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

Table A I -15. Matching Speed of Subject 15 in the Four Tasks (mm/s)

SS Task	20 mm/s	40 mm/s	60 mm/s	80 mm/s	100 mm/s	120 mm/s
T-T Task	25.40	44.20	58.20	74.40	86.80	100.60
T-V Task	23.41	40.17	59.26	68.33	101.95	99.65
V-T Task	29.40	42.00	61.40	74.00	95.40	102.60
V-V Task	21.66	37.27	53.67	66.01	92.78	90.78

SS: Standard stimulus speed;

MS: Matching speed

T-T Task: SS and MS were both presented by tactile stimulator;

T-V Task: SS was presented by tactile stimulator, while MS was presented by visual stimulator;

V-T Task: SS was presented by visual stimulator, while MS was presented by tactile stimulator;

V-V Task: SS and MS were both presented by visual stimulator.

II Individual behavior data of experiment 2

Table A II -1. Accuracy (%) of Subject 1 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	90.91	71.43	29.41
3	100	29.41	71.43	18.99
4	90.91	40.00	100	12.99
5	83.33	100	38.46	29.41

Table A II -2. Movement Time (s) of Subject 1 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.459	0.362	0.394	0.309
2	0.372	0.376	0.463	0.449
3	0.410	0.479	0.461	0.443
4	0.551	0.560	0.473	0.498
5	0.578	0.538	0.563	0.484

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -3. Accuracy of Subject 2 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	90.91	62.50	18.52
3	100	14.56	65.21	21.13
4	100	15.38	47.62	28.57
5	83.33	29.41	50.00	45.45

Table A II -4. Movement Time of Subject 2 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.319	0.316	0.347	0.300
2	0.361	0.409	0.381	0.344
3	0.511	0.461	0.359	0.381
4	0.560	0.464	0.436	0.383
5	0.731	0.485	0.616	0.466

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -5. Accuracy of Subject 3 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	90.91
3	100	62.50	88.24	75.00
4	90.91	55.56	83.33	16.39
5	100	4.63	55.56	6.58

Table A II -6. Movement Time of Subject 3 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.323	0.284	0.191	0.284
2	0.403	0.416	0.243	0.211
3	0.566	0.447	0.342	0.306
4	0.528	0.516	0.452	0.491
5	0.563	0.525	0.416	0.516

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -7. Accuracy of Subject 4 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	62.50	100	76.92
3	100	93.75	39.47	39.47
4	100	66.67	18.87	27.03
5	100	26.32	45.45	23.81

Table A II -8. Movement Time of Subject 4 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.215	0.369	0.247	0.381
2	0.375	0.441	0.328	0.317
3	0.478	0.389	0.387	0.322
4	0.459	0.455	0.547	0.477
5	0.541	0.634	0.425	0.497

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -9. Accuracy of Subject 5 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	66.67
3	100	44.12	88.24	37.50
4	83.33	100	100	71.43
5	100	27.78	62.50	35.71

Table A II -10. Movement Time of Subject 5 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.356	0.469	0.384	0.422
2	0.405	0.480	0.511	0.383
3	0.443	0.490	0.456	0.451
4	0.475	0.577	0.606	0.498
5	0.584	0.675	0.599	0.584

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -11. Accuracy of Subject 6 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	100	100	100	42.86
4	100	83.33	100	52.63
5	100	7.69	83.33	15.63

Table A II -12. Movement Time of Subject 6 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.247	0.325	0.228	0.303
2	0.266	0.356	0.313	0.264
3	0.365	0.325	0.401	0.412
4	0.386	0.456	0.464	0.481
5	0.503	0.650	0.519	0.622

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -13. Accuracy of Subject 7 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	66.67	100	100
3	100	100	83.33	65.22
4	100	71.43	100	66.67
5	100	100	100	71.43

Table A II -14. Movement Time of Subject 7 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.128	0.319	0.222	0.197
2	0.263	0.391	0.222	0.261
3	0.320	0.396	0.447	0.306
4	0.378	0.450	0.533	0.492
5	0.366	0.653	0.491	0.541

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -15. Accuracy of Subject 8 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	100	51.72	100	93.75
4	100	21.28	100	55.56
5	100	12.82	71.43	45.45

Table A II -16. Movement Time of Subject 8 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.543	0.484	0.622	0.431
2	0.431	0.487	0.673	0.724
3	0.466	0.771	0.613	0.734
4	0.801	0.778	0.642	0.616
5	0.869	0.778	0.981	0.694

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -17. Accuracy of Subject 9 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	100
3	100	93.75	93.75	78.95
4	76.92	43.48	90.91	66.67
5	100	45.45	62.50	13.51

Table A II -18. Movement Time of Subject 9 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.415	0.416	0.429	0.313
2	0.448	0.464	0.455	0.419
3	0.506	0.575	0.499	0.507
4	0.655	0.658	0.563	0.566
5	0.681	0.735	0.728	0.619

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -19. Accuracy of Subject 10 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	93.75	78.95	100	75.00
4	100	83.33	71.43	50.00
5	100	26.32	100	29.41

Table A II -20. Movement Time of Subject 10 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.250	0.238	0.300	0.210
2	0.261	0.288	0.400	0.351
3	0.308	0.488	0.322	0.424
4	0.491	0.669	0.366	0.342
5	0.697	0.631	0.625	0.519

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -21. Accuracy of Subject 11 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	41.67	100	90.91
3	100	88.24	100	68.18
4	90.91	83.33	90.91	62.50
5	83.33	27.78	83.33	55.56

Table A II -22. Movement Time of Subject 11 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.2564	0.3656	0.216	0.3252
2	0.3795	0.5064	0.358	0.3266
3	0.483267	0.421733	0.5074	0.412467
4	0.4391	0.5595	0.5484	0.5579
5	0.5998	0.6876	0.4936	0.6248

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -23. Accuracy of Subject 12 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	62.50
3	100	27.78	78.95	46.88
4	90.91	52.63	66.67	55.56
5	55.56	27.78	33.33	45.45

Table A II -24. Movement Time of Subject 12 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.409	0.412	0.356	0.397
2	0.419	0.467	0.459	0.477
3	0.478	0.694	0.579	0.546
4	0.686	0.778	0.622	0.611
5	0.809	0.844	0.784	0.740

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -25. Accuracy of Subject 13 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	90.91
3	93.75	88.24	100	46.88
4	100	83.33	100	100
5	100	71.43	83.33	100

Table A II -26. Movement Time of Subject 13 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.459	0.416	0.400	0.387
2	0.395	0.481	0.566	0.470
3	0.471	0.622	0.582	0.631
4	0.636	0.755	0.586	0.589
5	0.813	0.841	0.878	0.644

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -27. Accuracy of Subject 14 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	43.48	76.92	76.92
3	93.75	20.27	62.50	37.50
4	66.67	37.04	83.33	62.50
5	100	62.50	29.42	55.56

Table A II -28. Movement Time of Subject 14 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.325	0.487	0.372	0.362
2	0.403	0.577	0.419	0.423
3	0.483	0.522	0.477	0.444
4	0.523	0.580	0.530	0.544
5	0.562	0.697	0.534	0.560

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -29. Accuracy of Subject 15 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	90.91	100	90.91	83.33
3	100	83.33	100	60
4	71.43	55.56	83.33	83.33
5	62.50	4.63	55.56	21.74

Table A II -30. Movement Time of Subject 15 in the Elderly Adults

Task ID	FV	NM	NT	NV
1	0.159	0.259	0.197	0.203
2	0.261	0.280	0.227	0.216
3	0.278	0.296	0.311	0.245
4	0.311	0.305	0.336	0.319
5	0.306	0.341	0.344	0.290

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -31. Accuracy of Subject 1 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	100
3	100	88.24	100	68.18
4	100	66.67	90.91	47.62
5	71.43	41.67	83.33	29.41

Table A II -32. Movement Time of Subject 1 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.247	0.281	0.372	0.253
2	0.284	0.230	0.341	0.417
3	0.301	0.476	0.328	0.381
4	0.497	0.441	0.355	0.344
5	0.487	0.409	0.519	0.350

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -33. Accuracy of Subject 2 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	90.91	100	100	90.91
3	88.24	71.43	53.57	55.56
4	62.50	41.67	66.67	83.33
5	83.33	10.87	83.33	45.45

Table A II -34. Movement Time of Subject 2 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.150	0.185	0.191	0.159
2	0.181	0.177	0.203	0.233
3	0.207	0.227	0.233	0.229
4	0.289	0.252	0.242	0.228
5	0.300	0.259	0.323	0.269

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -35. Accuracy of Subject 3 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	76.92
3	100	60.00	100	45.45
4	76.92	45.45	71.43	29.41
5	100	27.78	100	31.25

Table A II -36. Movement Time of Subject 3 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.328	0.391	0.472	0.360
2	0.375	0.461	0.423	0.488
3	0.454	0.531	0.478	0.504
4	0.644	0.641	0.542	0.578
5	0.566	0.697	0.625	0.587

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -37. Accuracy of Subject 4 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	90.91	71.43
3	93.75	55.5	68.18	34.88
4	66.67	34.48	90.91	58.82
5	50.00	8.93	33.33	27.78

Table A II -38. Movement Time of Subject 4 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.116	0.206	0.150	0.228
2	0.259	0.247	0.161	0.191
3	0.272	0.240	0.329	0.214
4	0.288	0.292	0.353	0.331
5	0.344	0.438	0.278	0.394

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -39. Accuracy of Subject 5 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	90.91
3	93.75	93.75	100	83.33
4	83.33	27.78	100	71.43
5	100	5.05	83.33	55.56

Table A II -40. Movement Time of Subject 5 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.253	0.306	0.319	0.275
2	0.294	0.320	0.333	0.388
3	0.356	0.441	0.427	0.405
4	0.508	0.456	0.439	0.472
5	0.550	0.484	0.610	0.488

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -41. Accuracy of Subject 6 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	100	65.22	100	93.75
4	90.91	13.16	100	55.56
5	83.33	9.10	100	41.67

Table A II -42. Movement Time of Subject 6 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.194	0.250	0.278	0.269
2	0.245	0.317	0.300	0.275
3	0.313	0.349	0.360	0.362
4	0.347	0.475	0.416	0.464
5	0.503	0.544	0.453	0.494

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -43. Accuracy of Subject 7 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	76.92
3	93.75	60.00	62.50	40.54
4	100	30.30	76.92	55.56
5	71.43	25.00	50.00	22.73

Table A II -44. Movement Time of Subject 7 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.26	0.28	0.28	0.33
2	0.30	0.37	0.36	0.36
3	0.40	0.41	0.40	0.43
4	0.47	0.49	0.47	0.45
5	0.49	0.55	0.52	0.50

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -45. Accuracy of Subject 8 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	83.33	83.33	100
3	68.18	48.39	71.43	50.00
4	83.33	55.56	47.62	43.48
5	62.50	26.32	33.33	33.33

Table A II -46. Movement Time of Subject 8 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.191	0.194	0.241	0.203
2	0.241	0.250	0.259	0.364
3	0.269	0.482	0.276	0.357
4	0.594	0.550	0.305	0.325
5	0.594	0.353	0.532	0.328

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -47. Accuracy of Subject 9 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	90.91	100	83.33
3	100	71.43	88.24	44.12
4	100	76.92	83.33	50.00
5	71.43	35.71	55.56	41.67

Table A II -48. Movement Time of Subject 9 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.219	0.338	0.259	0.385
2	0.270	0.398	0.305	0.306
3	0.351	0.376	0.434	0.369
4	0.328	0.445	0.456	0.480
5	0.441	0.556	0.466	0.544

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -49. Accuracy of Subject 10 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	83.33	83.33	55.56
3	88.24	68.18	51.72	27.27
4	66.67	83.33	62.50	22.22
5	62.50	17.86	31.25	50.00

Table A II -50. Movement Time of Subject 10 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.175	0.213	0.203	0.203
2	0.187	0.245	0.238	0.247
3	0.234	0.294	0.273	0.279
4	0.333	0.339	0.322	0.309
5	0.347	0.412	0.356	0.338

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -51. Accuracy of Subject 11 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	100	93.75	100	71.43
4	100	62.50	76.92	50.00
5	83.33	45.45	100	41.67

Table A II -52. Movement Time of Subject 11 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.182	0.197	0.231	0.206
2	0.217	0.219	0.269	0.266
3	0.241	0.281	0.286	0.314
4	0.349	0.333	0.327	0.341
5	0.350	0.372	0.388	0.394

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -53. Accuracy of Subject 12 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	83.33	83.33
3	100	83.33	88.24	50.00
4	90.91	58.82	100	83.33
5	83.33	7.46	62.50	15.63

Table A II -54. Movement Time of Subject 12 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.159	0.185	0.194	0.169
2	0.236	0.256	0.230	0.241
3	0.291	0.282	0.360	0.277
4	0.367	0.354	0.371	0.381
5	0.431	0.500	0.359	0.431

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -55. Accuracy of Subject 13 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	100	100	100	100
3	100	20.55	88.24	88.24
4	100	55.56	90.91	47.62
5	100	50.00	62.50	16.13

Table A II -56. Movement Time of Subject 13 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.182	0.259	0.263	0.306
2	0.228	0.352	0.303	0.349
3	0.290	0.432	0.367	0.412
4	0.342	0.409	0.470	0.462
5	0.503	0.594	0.612	0.547

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -57. Accuracy of Subject 14 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	90.91	90.91	100	76.92
3	93.75	68.18	93.75	55.56
4	58.82	40	90.91	83.33
5	83.33	35.71	100	62.50

Table A II -58. Movement Time of Subject 14 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.156	0.193	0.190	0.150
2	0.233	0.200	0.216	0.227
3	0.253	0.231	0.318	0.249
4	0.384	0.350	0.286	0.352
5	0.550	0.331	0.403	0.293

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Table A II -59. Accuracy of Subject 15 in the Young Adults

Task ID	FV	NM	NT	NV
1	100	100	100	100
2	83.33	100	100	83.33
3	93.75	83.33	93.75	53.57
4	100	62.50	90.91	55.56
5	71.43	62.50	100	100

Table A II -60. Movement Time of Subject 15 in the Young Adults

Task ID	FV	NM	NT	NV
1	0.169	0.228	0.225	0.215
2	0.215	0.306	0.285	0.319
3	0.314	0.460	0.401	0.407
4	0.384	0.602	0.531	0.533
5	0.519	0.700	0.647	0.650

FV: Full visual feedback of hand movement and target location;

NM: No visual feedback of hand movement;

NT: No visual feedback of target location;

NV: No visual feedback of hand movement and target location condition;

ID: The index of difficulty

Publications

Refereed papers

- [1] **Liancun Zhang**, Jiajia Yang, Yoshinobu Inai, Qiang Huang, Jinglong Wu. Effects of aging on pointing movements under restricted visual feedback conditions. Human Movement Science, Vol. 40, No. 6, pp.1-13, 2015.
- [2] **Liancun Zhang**, Jiajia Yang, Yinghua Yu, Satoshi Takahashi, Yuta Araki, Qiang Huang, Jinglong Wu. Speed matching interaction between visual and tactile motion. Neuroscience and Biomedical Engineering, Vol. 3, No. 1, pp.20-26, 2015.

Related achievements

1. Papers

- [1] **Liancun Zhang**, Qiang Huang, Yue Li, Junyao Gao, Hui Li, Liying Wu. Miniature detection robotic system with rapid deployment mode. IEEE International Conference on Automation and Logistics, pp.1254-1259, 2012.
- [2] **Liancun Zhang**, Qiang Huang, Junyao Gao, Yue Li, Weimin Zhang, Liying Wu. Design of aerial dispersal miniature detection robotic system. IEEE International Conference on Information and Automation, pp.7-12, 2012.
- [3] **Liancun Zhang**, Qiang Huang, Weimin Zhang, Yue Li, Yuancan Huang, Hui Li,

Liying Wu. Design and realization for throwable semi-autonomous reconnaissance robot. IEEE International Conference on Automation and Logistics, pp.6-11, 2011.

2. Patent

- [1] Qiang Huang, **Liancun Zhang**, Yue Li, Junyao Gao. An anti-overload mechanism for enhancing anti-impact capability of miniature detecting robot. ZL 201210232778.6, 2015.3 (China Patent)
- [2] Qiang Huang, **Liancun Zhang**, Yue Li, Junyao Gao, Jingchao Zhao, Yuancan Huang. Attitude adjusting mechanism of the throwable miniature reconnaissance robot. ZL 201010049293.4, 2014.6 (China Patent)
- [3] Qiang Huang, **Liancun Zhang**, Junyao Gao, Yuancan Huang, Yue Li, Jingchao Zhao. All-dimensional anti-impact rubber-tired wheels. ZL 201010246091.9, 2014.3 (China Patent)
- [4] Qiang Huang, **Liancun Zhang**, Junyao Gao, Yue Li, Jingchao Zhao, Yuancan Huang. The flexible driving mechanism with all dimensional anti-impact of the axial independent and radial-relate. ZL 201010049294.9, 2014.1 (China Patent)
- [5] Yuancan Huang, Qiang Huang, Yue Li, **Liancun Zhang**, Wenhua Sang, Tao Sun. All-dimensional split type anti-impact rubber-tired wheels. ZL 201010246094.2. 2013.4 (China Patent)

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