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# Changes in Reaction Time during Mental Rotation of Three-Dimensional Objects for Chronic Hemiparetic Stroke

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# 3차원 물체의 심상회전이 만성 편마비 뇌졸중 환자의 반응시간에 미치는 영향

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**Abstract** There is a cause and effect relationship in that brain injury causes impairment of mental rotation and ultimately independent functional activities. The purpose of this study was to compare the effects of mental rotation on reaction time and precision between the normal adults and chronic hemiparetic stroke patients. Thirty-one patients with chronic hemiparetic stroke and twenty normal adults participated in this study. The participants conducted 2 types of tasks for mental rotation: a comparison task using mirror images, and a rotation task using angular disparity images for 2 different 3-dimensional objects. Each of the 3 possible angled shapes (90°, 180°, and 270°) appeared in each pair. The test consisted of 6 mirror-reflected image pairs and 6 angular disparity image pairs visualized during angular rotation, and 12 test periods. The subjects were judged on how accurately and rapidly they could distinguish between the mirrored and non-mirrored pairs. The study measured reaction time and precision to compare the effect of mental rotation tasks. Reaction time during all 3 angular conditions were significantly longer in the stroke patients than that in the normal adult during the comparison tasks and the rotation tasks. In addition, precision during mental rotation tasks was not significantly different between normal adults and stroke patients. Our results suggest that rehabilitation therapists should keep in mind that mental rotation is more difficult in stroke population than in normal adults.

**요 약** 심상회전은 어떤 대상이나 형태를 심상으로 하나의 각도에서 다른 각도로 회전시키는 활동으로, 일상생활동작을 수행할 때 환경과 자신에 대한 위치 및 움직임을 계획하는 단계에서 필요한 기능 중 하나이다. 본 연구는 정상인과 만성 편마비환자를 대상으로 반응시간(reaction time)과 정답율(precision)에 심상회전과제가 미치는 영향을 알아보고, 임상에서 편마비 환자를 치료할 때 심상회전능력의 변화가 과제수행에 장애요인이 될 수 있는지를 알아보기 위함이다. 본 연구는 만성 편마비 환자 31명과 정상성인 20명이 참여하였다. 연구대상자는 거울상(mirror image)을 이용한 대조과제(comparison task)와 각도불일치상(angular disparity image)을 이용한 회전과제(rotation task) 등의 2 가지 유형의 심상회전과제를 수행하였다. 검사자는 대상자에게 한 쌍의 상에 대하여 동일한 상인지 아닌지를 '예'와 '아니오'로 가능한 한 빠르게 대답하라고 요구하였고, 상을 노출한 시간부터 대상자가 대답한 시간까지의 반응시간과 정답률을 측정하였다. 대조과제 및 회전과제에 대한 반응시간은 편마비 환자에서 정상인에 비하여 유의하게 느리게 나타났다. 그러나 편마비 환자와 정상인은 심상회전과제에 대한 정답율에서 유의한 차이를 보이지 않았다. 본 연구에서 편마비 환자군과 정상군 모두에서 쌍을 이룬 상의 각이 불일치할 때 반응시간이 느리게 나타났지만, 정상군보다 편마비 환자군에서 심상회전에 오랜 시간이 걸렸다. 따라서 재활과정에서 편마비 환자를 대상으로 치료계획을 수립하고 치료를 할 때, 회전각도를 이용한 난이도 조절이 가능할 것으로 사료된다. 또한 본 연구결과는 정상인에 비하여 편마비 환자의 심상회전에 차이가 있다는 것을 재활과정에서 치료사는 염두 해 두어야 한다고 제안한다.

**Key Words :** Hemiparesis, Mental rotation, Precision, Reaction time, Stroke

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# 1. Introduction

Stroke is a leading cause of chronic disability in many developed countries, and 80% of stroke survivors experience hemiparesis early following stroke[1]. Primary impairments resulting from stroke affect many human functions, such as sensation, motor, movements, postural control, speech, language, and swallowing, as well as perception and cognition[2]. Perceptive and cognitive dysfunctions are considered to encompass impairments in attention and concentration, memory, orientation, executive function, and visual-spatial perception[2, 3].

Spatial relations syndrome is a severe spatial deficit, which includes loss of figure-ground discrimination, form constancy, spatial relations of depth and distance in near and far space, position in space, and topographical orientation[4, 5]. This syndrome causes disturbances in the daily activities of stroke patients, such as tripping on pavement curbs, dropping utensils off the edge of tables, and difficulty in distinguishing the top, bottom, inside, and outside of clothing. Thus, spatial relations syndrome can reduce the ability to perform independent daily activities, ultimately impeding instrumental activities, such as housework and social interactions[6, 7]. This is associated with a need for ongoing care and support by caregiver and society[2]. Therefore, it is important for researchers and clinicians in rehabilitation fields to identify effective examinations, evaluations, and interventions to treat spatial relations syndrome following stroke.

Mental rotation has been studied within the context of visuospatial skills and disorders[8, 9, 10]. However, a number of findings indicate that this process shares certain characteristics with voluntary actions. For example, mental rotation does not occur automatically when people look at a rotated display; rather, it can be started and stopped at will, and its speed can be controlled to some extent[11, 12]. Many theoretical and clinical studies have been reported recently for nonverbal internal representation, particularly mental imagery. The primary focus of the previous studies has been concerned with the functional significance of mental imagery or the effects of motor imagery on functional activities[13, 14]. Therefore, there is an accepted cause-effect relationship in that brain injury causes impairment of mental rotation, and ultimately impairment of independent functional activities. Studies measuring changes in mental rotation depending on degree of angular rotation have also been conducted on normal adults[15, 16]. However, there are no full studies describing mental rotation tasks in individuals with stroke. The purpose of this study was to compare the effects of mental rotation on reaction time and precision between normal adults and stroke patients. This study was also to evaluate whether mental rotation controls progressive difficulty of treatment protocol in therapeutic exercise for independent functional activities in individuals with chronic hemiparetic stroke.

# 2. Methods

## 2.1 subjects

Twenty normal adults (6 male, 14 female; mean age 53.0 years) at S dementia center participated in this study. Thirty-one patients with chronic hemiparetic stroke (15 male, 16 female; mean age 47.8 years) were also recruited through visits to D Hospital and met the following inclusion criteria: 1) a history of a single stroke, at least 6 months before the start of the study; 2) absence of severe cognitive impairment (scores above 18 on the Mini-Mental State Examination); 3) ability to understand verbal instructions; and 4) no significant body or visuospatial hemineglect[14, 17]. Exclusion criteria were having other neurologic disease, severe depression, and being on antidepressants. All subjects signed an informed consent form after they received study information.

General characteristics of stroke patients were as follows: 1) mean duration of disease 47.0 months; 2) the number of Brunnstrom's stage 3, 4, and 5 is 10, 15, and 6 respectively; 3) cerebral infarction (15 persons), brainstem infarction (5 persons), and cerebral hemorrhage (8 persons); 4) the mean score of mini-mental state examination and modified Barthel index was 25.0 and 78.0; 5) mean score of manual functional test in more and less affected side was 14.5 and 28.5 (Table 1).

[Table 1] Clinical and demographic characteristics of the study participants

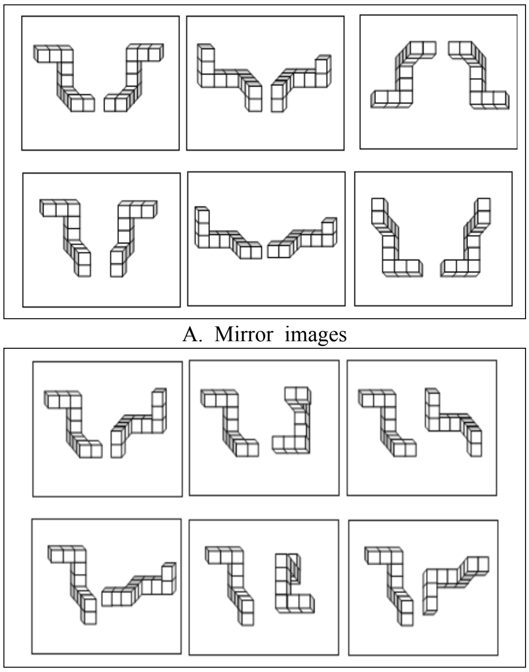
(N=51)

| Characteristics | Normal adults (n=20) | Stroke patients (n=31) |
|---|---|---|
| Sex (n)% | | |
| Male | 6(30.0) | 15(48.4) |
| Female | 14(70.0) | 16(51.6) |
| Age, yrs | 53.0±7.5 | 47.8±15.8 |
| Post-stroke duration, mos | N/A | 47.0±39.9 |
| Brunnstrom's stage n(%) | | |
| Stage 3 | N/A | 10(32.2) |
| Stage 4 | | 15(48.4) |
| Stage 5 | | 6(19.4) |
| Diagnosis n(%) | | |
| Cerebral infarction | N/A | 18(58.1) |
| Brainstem infarction | | 5(16.1) |
| Intracerebral hemorrhage | | 8(25.8) |
| Hemiparetic side, n(%) | | |
| Left | N/A | 15(48) |
| Right | | 16(52) |
| Mini-Mental State Examination | N/A | 25.0±3.9 |
| Modified Barthel Index | N/A | 78.0±18.0 |
| Manual Function Test | | |
| More affected side | N/A | 14.5±8.5 |
| Less affected side | | 28.5±2.3 |

/A, not available.

## 2.2 Procedure

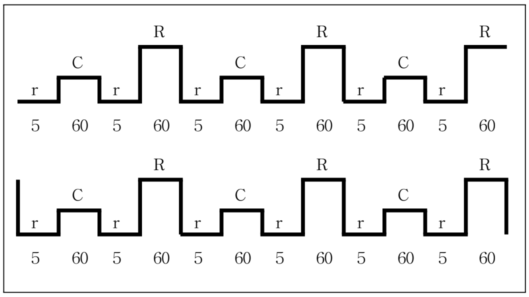
The participants conducted 2 types of tasks for mental rotation: a comparison task using mirror images, and a rotation task using angular disparity images for 2 different 3-dimensional (3-D) objects[18]. Each 3-D object consisted of 10 solid cubes attached face-to-face to form a rigid arm-like structure with exactly three right-angled elbows. The mirror image was a pair of 3-D objects, one was identical and another was mirror-reflected shapes. Each of the three possible angled shapes (90°, 180°, and 270°) appeared in each pair. Angular disparity images consisted of two different shapes; the left-hand object was the standard version always presented vertically, while the right-hand object was presented at three possible angles: 90°, 180°, and 270°. The test consisted of six mirror-reflected image pairs and six angular disparity image pairs visualized during angular rotation. The twelve shapes used as stimuli are illustrated in Fig 1.


A. Mirror images

B. Angular disparity images

[Fig. 1] Mirror and angular disparity images used for the mental rotation task.

The subjects were asked to compare two different 3-D objects, determine if they were mirror images or if they were the same image, and respond as quickly and accurately as possible by saying "Yes" or "No". The protocol for the mental rotation tasks interleaved six separate mirror images, six angular disparity trials, and 12 rest periods. The protocol alternated between mirror and angular disparity images, which were presented in blocks of 60-second duration, separated by 5-second resting periods. That is, each image was shown once on a computer screen for up to 60 seconds, followed by a 5-second rest periods (Fig. 2). Subjects were asked to proceed to the next step when they were unable to complete the task within 60 seconds, and reaction time was recorded 60 seconds and accuracy was recorded error. Each trial lasted approximately 13 minutes. The order of comparison and rotation tasks was randomized for each test. The subjects were judged on how accurately (accuracy) and rapidly (reaction time) they could distinguish between the mirrored and non-mirrored pairs. Four practice trials were carried out prior to the 6 testing periods.




[Fig. 2] Schematic of testing procedure. C, comparison task; R, rotatory task; r, rest.

The experiment was conducted on an X-note R570 computer with a 21-inch built-in monitor (LG Inc., Seoul, Korea). This study also measured the reaction time using an electrical timer connected to a computer to obtain values from the digital signals.

### 2.3 Outcome Measures

This study measured reaction time and precision to compare the effect of mental rotation tasks. Reaction time is defined as “a measure of the time from the arrival of a suddenly presented and unanticipated signal to the beginning of the response to it”. This study defined reaction time as the time from commencement of visual display (e.g., immediately after the resting period) to the moment subjects answered yes or no. Only rotation trials where subjects provided a correct response were included, and outliers (a time more than 2 standard deviations from the mean of the times in that condition for that subject) were removed from the dataset prior to analysis. Precision was defined as the proportion of true positives against all positive results (both correct and incorrect trials). This study calculated precision as follows: Precision = (number of correct answers / number of all answers) x 100.

### 2.4 Statistical Analysis

The independent variables of this study were comparison and rotatory tasks during 6 conditions, and the dependent variables were reaction time (seconds) and precision (%). Independent t-tests were used to determine the significant differences between normal and stroke groups in terms of reaction time and precision. The dependent variables across the twelve different mirror and angular disparity images were compared using one-way repeated measure ANOVA ($p<0.05$). Fisher's least significant difference (LSD) was used for the post-hoc analysis in order to identify difference among image tests (90°, 180°, and 270°). Demographic values and cognitive functions in normal adults and stroke patients were tested with descriptive statistics. All analyses were performed using SPSS software (SPSS Inc., Chicago, IL) version 18.0.

## 3. Results

Reaction times during all 3 angular conditions were significantly greater in the stroke group than in the normal adult group during the comparison tasks (Table 2). The result of the post-hoc test using Fisher's LSD revealed that reaction time during the 90° rotation condition was significantly greater than that during the 180° rotation condition in stroke subjects. In addition, the reaction time during the 270° rotation condition was significantly greater than that during the 180° rotation condition in stroke subjects (Fig. 1B).

[Table 2] Reaction time during comparison task in normal adult and stroke subjects

(N=51)

| Angle | Normal adult (n=20) | Stroke subject (n=31) | t | P-value |
|---|---|---|---|---|
| 90° | 4.7±1.6* | 7.2±2.4 | 4.049 | <.001 |
| 180° | 4.0±1.2 | 6.2±2.4 | 3.981 | <.001 |
| 270° | 4.6±1.4 | 8.3±2.7 | 5.739 | <.001 |
| F | 5.461 | 13.147 | | |
| P-value | 0.014 | <0.001 | | |

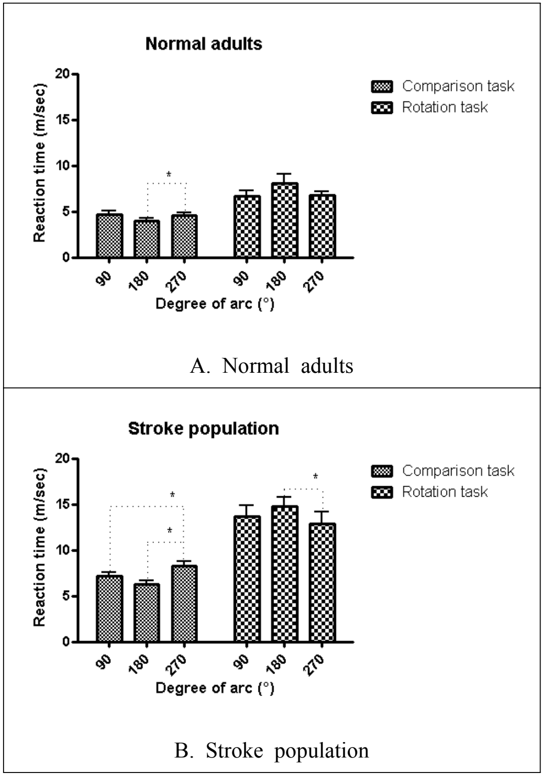
*mean±standard deviation

The reaction time during the 3 angular disparities in rotation tasks was significantly longer in the stroke group than in the normal adult group. However, the reaction time during rotation was not significantly different among the 3 angular disparity conditions in both groups (Table 3).

[Table 3] Reaction time during rotation task in normal adult and stroke subjects (N=51)

| Angle | Normal adult (n=20) | Stroke subject (n=31) | t | P-value |
|---|---|---|---|---|
| 90° | 6.6±3.2* | 13.7±6.8 | 4.321 | <.001 |
| 180° | 8.1±4.5 | 14.8±5.2 | 4.769 | <.001 |
| 270° | 6.7±2.1 | 12.8±7.7 | 3.441 | .001 |
| F | 1.560 | 2.526 | | |
| P-value | 0.237 | 0.97 | | |

*mean±standard deviation




A. Normal adults

B. Stroke population

[Fig. 3] Reaction time on two mental rotation tasks. This figure depicts the reaction time on rotational task. *compared between angular rotational conditions $p<.05$.

Lastly, precision during mental rotation tasks was not significantly different between normal adults and stroke subjects (Table 4).

[Table 4] Precision on mental rotation tasks (N=51)

| | Normal adults (n=20) | Stroke subjects (n=31) | t | P-value |
|---|---|---|---|---|
| Comparison task | 89.2±12.4 | 78.5±23.6 | -1.856 | .070 |
| Rotation task | 60.8±20.4 | 53.8±23.1 | .459 | .270 |

*mean±standard deviation

## 4. Discussion

The aim of this study was to evaluate the effects of mental rotation on reaction time and precision in persons with chronic hemiparetic stroke. The main findings were as follows: Firstly, reaction time was significantly greater in the stroke group than in the normal group for mental rotation, comparison, and rotation tasks; secondly, reaction time was significantly different among the 3 angular rotation conditions during the comparison task in both groups; and thirdly, reaction time was not significantly different among the 3 angular rotation conditions during the rotation task. Finally, precision was not significantly different on the mental rotation tasks in both groups.

Approximately one third stroke survivors are affected by visual-perceptual deficits, which involve disorders of body schema or body image, spatial relations, and agnosia[19]. Moreover, visual perception is considered an essential foundation for performance of all human movement, and is necessary for independent daily living and occupational ability, ultimately integrating most of social works for stroke populations[20]. One of the main measurement tools and treatment methods for stroke patients is mental rotation[21].

The mental rotation is one of the main measurement tools and treatment methods to examine the awareness of objects in 3-D environment for stroke patients. Mental rotation is "a genuine transformation process, in which a shape is represented as passing through intermediate orientations before reaching the target orientation," and has a positive effect in training physical activities[12]. This study used 2 types of mental rotation tasks for evaluating differences between normal adults and stroke patients.

Reaction time, measured from the detection of sensory input to the beginning of movement behavior, is one of many methods to determine human information processing, involving sensory detection and identification, response selection and programming, and executive function. Therefore, reaction time assesses the process from sensory information entering sensory receptors, being processed in the central nerve system, and descending from order centers to peripheral body parts, initiating movement[22]. The results of this study suggest that stroke patients may have more difficulty with mental rotation tasks than normal adults would. In this study, increased reaction time in stroke population may be caused by various degrees of impairment in sensory receptors, exteroceptors, interoceptors, and proprioceptors, as well as brain injury. Sensory information is frequently impaired but rarely absent on the hemiplegic side following stroke, and can range from loss of superficial and/or deep sensations to impairments in the combined cortical sensations. Sensory dysfunction can contribute to difficulty in detecting sensory demands from internal and/or surrounding environmental components before, during, or after performing movements[23]. Therefore, changes in sensory information can contribute to decreased reaction time in stroke subjects.

In this study, reaction time was fastest during the 180° rotation compared to that during other angular movements for the comparison task using mirror images in both normal and stroke groups. However, angular disparity during the rotation task was slowest during the 180° condition compared to other angular conditions in both normal and stroke groups. Findings from previous studies that have examined the relationship between reaction time of mental rotation and rotational degree during mental rotation task have been controversial[11, 15]. Shepard and Metzler found that reaction time during mental rotation tasks increased linearly in 20° increments from 0° to 180° in normal adults. According to Cheung et al., reaction time in healthy adults decreased as angular rotation increased in 40° from 80° to 160° during mental rotation. The present study produced results similar to the study by Cheung et al., although the angular incremental rate differed.

These results also show that intra-group reaction times differed according to the types of mental rotation, comparison, or rotation tasks. The reaction time for the mirror-reversed images was greater than that for the angular disparity images in both groups. Mental rotation for mirror-reversed images is generally more monotonic than that for angular disparity images. Mental rotation using angular disparity images should have matched the instantaneous orientation of subjects changing images through mental rotation of a shape.

There is a reason subjects required more time when they were told to rotate a shape mentally and a probe stimulus was presented at a time and orientation that should have matched the instantaneous orientation of their changing image: the time they took to discriminate the handedness of the probe was relatively insensitive to its absolute orientation.

This study also measured precision during mental rotation tasks to examine whether the pattern of reaction time results was due to a speed-accuracy trade-off, meaning simply that when subjects attempted to do something more quickly, they typically did it less accurately[22]. The results show that precision was not significantly different between normal and stroke groups during the 3 angular rotation conditions during mental rotation tasks in this study. Therefore, changes in reaction time according to degrees of angular rotation were not influenced by accuracy during the mental rotation task. In this study, we provided each image for 60 seconds, but subjects in the stroke group needed an average of <20 seconds between detecting sensory information and answering yes/no. The lack of significant differences between the 2 groups is thought to be due to the long display time.

Mental rotation is necessary for independent functional activities. Our results suggest that occupational therapists should keep in mind that mental rotation is more difficult in stroke population than in normal adults in rehabilitation fields. The aim of this study was to compare mental rotation abilities between normal adults and stroke persons. In future studies, it may be worthwhile to investigate whether mental rotation abilities depend on the extent or areas of brain damage. This study used unfamiliar objects in our living environment, but perhaps the use of familiar images should be investigated in future studies, as this could influence reaction time during mental rotation.

## 5. Conclusion

Mental rotation is a genuine transformation process, in which a shape is represented as passing through intermediate orientations before reaching the target orientation, and has a positive effects in functional activities training. For stroke patients, it is necessary for independent daily living and occupational activities, ultimately integrated social works before brain damage. The results of this study show that stroke subjects would have more difficulty with mental rotation tasks than that of normal adults. The results suggest that increased in reaction time in stroke population may be caused by various degrees of impairment in sensory information and brain damage, and occupational therapists should keep in mind that mental rotation is more difficult in stroke population than in normal adults in establishing plan of cares as well as doing exercises for hemiparetic stroke.

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