

# Changes in Event-Related Potentials Related to Pattern Recognition of Teeth in Dental Students

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## **Abstract**

This study investigated brain cognition using P300 for fundamental examination of information-processing modes generated in tooth, script, and hand discrimination by dental students. Subjects were 19 second-year dental students. The task was to differentiate a tooth, script character, or hand in each of a rotated series of line drawings. Images were presented at random using the oddball paradigm with a target-to-non-target ratio of 2:8, with the subject instructed to press a button only on observation of the target stimulus. Correct answer rate, reaction time, P300 amplitude, and P300 latency were analyzed using electroencephalography (EEG). Results of EEG were divided into waveform components, feature extraction of the waveform was performed, and the relevance of presented orientation was examined.

Reaction time was longest for the 180° orientation with all tasks. No differences in P300 latency were seen by presented orientation for any task, but P300 amplitude was smallest at 180° for all tasks. Script characters and hands at 0° were easily discriminated, but tooth did not show any orientation difference.

These findings suggest that discrimination in script and hand tasks was performed by top-down processing and bottom-up processing efficiently, and that discrimination in tooth task was intentionally performed in a bottom-up manner.

## **Introduction**

Pattern recognition (1) is a major part of clinical reasoning. Pattern recognition is determined by semantics using the concepts in memory for the given stimulus. The process of performing pattern recognition can involve top-down processing or bottom-up processing. The former involves information processing from analysis of the lower-order level of physical features without the involvement of experience. The latter involves information processing from a higher-order level based on concepts already in memory. Pattern recognition is also said to reflect the influence of attention and context (2,3).

Research methods for pattern recognition frequently use event-related potentials (ERP) (4-7) to clarify the nature of cognitive processes in the brain. Our previous pattern recognition research has revealed the following about tooth type differentiation using ERP. Oyama et al. (8) showed that profile is more important than margin and grooves, focusing on the participation of the anatomical feature at the time of performing dental pattern recognition. Ebihara (9) showed that tooth type differentiation involves mental rotation (10,11) of the image in order to match images of teeth in the brain. Moreover, he showed that the self-centered reference frame (12,13) contributes to the differentiation of left and right. Kuwahara et al. (14) showed that the degree of difficulty is higher for teeth than for script characters (15,16) and the cognitive information-processing process for teeth approximates that for hands (17,18).

Experiments to date have focused on the knowledge level of fifth-year dental students, who have undertaken patient training, utilizing their knowledge of

dental anatomy and various technical and clinical subjects. In other words, the cognitive information processes clarified to date have been those of subjects at a relatively high level of knowledge and experience among dental students. To continue to elucidate cognitive information processes, data must be obtained from individuals with varying levels of knowledge and experience.

The present research sought to clarify dental information-processing processes for students with only textbook knowledge of dental anatomy, without clinical knowledge or training.

## **Methods**

Subjects were 19 second-year dental students (mean age,  $19.5 \pm 1.3$  years; range, 19-23 years) who had already acquired knowledge of tooth anatomy. All subjects were right-handed, had no visual impediments to participate in the study, and had no history of psychiatric disorder.

The task of tooth type differentiation was based on the previous research of Kuwahara et al. (14). The present study made similar comparisons using "script" (15,16) as a category task and "hand" (17,18) as a related body schema task (19). Each subject was presented with line drawing images of a tooth, script character, or hand which did not include three-dimensional features. Images for each task are described below.

### 1) Tooth task

Each image represented a first molar viewed from above. The target stimulus was the right mandibular first molar. Non-target stimuli were the left maxillary, left mandibular, and right maxillary first molars. Images were presented with the buccal side topmost (as 0°) or rotated clockwise by 90°, 180°, or 270° (Fig. 1).

## 2) Script task

Japanese katakana characters were used for the script task, because katakana are composed of readily perceptible dot and line strokes.

The target stimulus was the conventional katakana character “ah” (ア). Non-target stimuli were the conventional katakana character “ma” (マ) and the mirror images of “ah” and “ma”. As in the other tasks, images were line drawings rotated clockwise by 0°, 90°, 180°, or 270° (Fig. 2).

## 3) Hand task

The target stimulus was a line drawing of a right hand with the second and third digits extended. Non-target stimuli were line drawings of a left hand with the second and third digits extended and a right and left hand each with the fourth and fifth digits extended. As in the other tasks, images were line drawings rotated clockwise by 0°, 90°, 180°, or 270° (Fig. 3).

To prevent subjects from reaching a judgment based on remembering only one part of an image and applying their judgment of that image to the current case, a white dot was marked in each image and the subject was instructed to first determine the orientation of the image and then to judge whether the image



represented the target stimulus.

Experiments were performed in a sealed room. The subject sat in a resting state with head immobilized. Each image (image size, 480×480 pixels) was presented on a monitor 50 cm in front of the subject. Images were presented one at a time randomly following the oddball paradigm by using a multi-trigger system (Multi-Trigger System; Medical Try System, Tokyo, Japan). The target stimulus and non-target stimuli were presented in a ratio of 2:8. The presentation time for each image was 1500 ms, and 500 presentations were performed per task. Subjects were instructed to press the specified button only on observation of the target stimulus and were unable to observe their own hands directly. Brainwave measurement was performed during answering together with electrooculography (EOG) to identify artifact indicators. Brainwaves were recorded by electroencephalography (EEG) (Synafit EE5800; NEC Medical Systems, Tokyo, Japan). The ERP waveform was extracted from the brainwaves and submitted for analytical processing. EEG was recorded from three locations (Fz, Cz, and Pz) based on the International EEG Society Association standard electrode placement (International 10-20 system), using silver and silver chloride electrodes, on the basis of linked earlobes. Pz was also examined because it provides an easily measured indicator of cognitive function. Experiments were performed under the following conditions at the time of measurement: contact impedance, <5 k $\Omega$ ; sampling frequency, 1000 Hz; low-frequency filter, 0.1 Hz; and high-frequency filter, 100 Hz.

The data were aggregated by task and orientation. The following items were recorded: correct answer rate, reaction time to button push from stimulus

presentation, and P300 latency and P300 amplitude from averaging the waveform of the target stimulus. Artifacts and noise were removed from the target stimulus. P300 is a positive-going wave with a scalp amplitude distribution with a latency of 300 to 600 ms, and P300 amplitude was taken as the maximum amplitude, while P300 latency was taken as the interval from stimulus onset to the vertex of the amplitude-determining P300 waveform. Moreover, P300 waveforms from stimulus onset to 300 ms and from 300 to 600 ms were obtained from the grand mean waveform. For each waveform, the relevance of presented orientation was examined. To avoid loading dependence on the order of image presentation, we changed the order of task performance after completion by each subject. The time to complete one task was about 20 min. Subjects were provided with a rest period of about 10 min between tasks to prevent fatigue. Subjects then rated task difficulty using a 100 mm visual analogue scale (VAS) at the end of the experiment.

Statistical analyses were performed using statistical software (SPSS Statistics version 21; IBM SPSS Japan, Tokyo, Japan). Comparisons between tasks were performed using the Mann-Whitney U test with Bonferroni adjustment ( $p < 0.017$ ). Comparisons between presented orientations in the task were performed using Wilcoxon signed-rank test ( $p < 0.008$ ). In addition, the association between presented orientation and waveform was examined using Spearman's rank correlation ( $p < 0.05$ ). The correlation coefficient is here interpreted as follows: a strong correlation is defined as  $0.7 < |r| \leq 1.0$ , a moderate correlation is  $0.4 < |r| \leq 0.7$ , a slight correlation is  $0.2 < |r| \leq 0.4$ , and almost no correlation is  $|r| \leq 0.2$ .

This study was performed with the approval of the ethics committee at Nihon

University School of Dentistry at Matsudo (Approval #EC11-010). The experiment was described in advance to subjects and performed only after obtaining written, informed consent.

## Results

### 1. Correct answers rate and VAS of tasks

The correct answer rate was  $95 \pm 5\%$  for tooth task,  $98 \pm 2\%$  for script task, and  $98 \pm 2\%$  for hand task. No significant differences were evident between tasks.

VAS score was  $56 \pm 29$  for tooth task,  $21 \pm 23$  for script task, and  $38 \pm 30$  for hand task (Table 1). A significant difference was evident between tooth and script tasks.

### 2. Correct answer rate by presented orientation

With tooth task, the correct answer rate was  $97 \pm 5\%$  for  $0^\circ$ ,  $93 \pm 10\%$  for  $90^\circ$ ,  $96 \pm 5\%$  for  $180^\circ$ , and  $95 \pm 6\%$  for  $270^\circ$ . No significant differences were evident.

With script task, the correct answer rate was  $100 \pm 1\%$  for  $0^\circ$ ,  $99 \pm 2\%$  for  $90^\circ$ ,  $96 \pm 5\%$  for  $180^\circ$ , and  $99 \pm 4\%$  for  $270^\circ$ . A significant difference was recognized between  $0^\circ$  and  $180^\circ$ .

With hand task, the correct answer rate was  $99 \pm 2\%$  for  $0^\circ$ ,  $95 \pm 8\%$  for  $90^\circ$ ,  $99 \pm 2\%$  for  $180^\circ$ , and  $99 \pm 1\%$  for  $270^\circ$ . No significant differences were seen. The results are shown in Table 2.

### 3. Reaction time by presented orientation

With tooth task, reaction time was  $707 \pm 97$  ms for  $0^\circ$ ,  $805 \pm 125$  ms for  $90^\circ$ ,  $843 \pm 127$  ms for  $180^\circ$ , and  $778 \pm 104$  ms for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$ , between  $0^\circ$  and  $180^\circ$ , between  $0^\circ$  and  $270^\circ$ , and between  $180^\circ$  and  $270^\circ$ .

With script task, reaction time was  $513 \pm 83$  ms for  $0^\circ$ ,  $624 \pm 91$  ms for  $90^\circ$ ,  $785 \pm 100$  ms for  $180^\circ$ , and  $638 \pm 102$  ms for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$ , between  $0^\circ$  and  $180^\circ$ , between  $0^\circ$  and  $270^\circ$ , between  $90^\circ$  and  $180^\circ$ , and between  $180^\circ$  and  $270^\circ$ .

With hand task, reaction time was  $670 \pm 125$  ms for  $0^\circ$ ,  $812 \pm 150$  ms for  $90^\circ$ ,  $800 \pm 101$  ms for  $180^\circ$ , and  $707 \pm 107$  ms for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$ , between  $0^\circ$  and  $180^\circ$ , between  $90^\circ$  and  $270^\circ$ , and between  $180^\circ$  and  $270^\circ$ . The results are shown in Fig. 4.

### 4. P300 latency by presented orientation

With tooth task, P300 latency was  $412 \pm 85$  ms for  $0^\circ$ ,  $452 \pm 76$  ms for  $90^\circ$ ,  $447 \pm 82$  ms for  $180^\circ$ , and  $433 \pm 96$  ms for  $270^\circ$ . No significant differences were evident.

With script task, P300 latency was  $420 \pm 59$  ms for  $0^\circ$ ,  $438 \pm 76$  ms for  $90^\circ$ ,  $429 \pm 95$  ms for  $180^\circ$ , and  $436 \pm 86$  ms for  $270^\circ$ . No significant differences were evident.

With hand task, P300 latency was  $416 \pm 73$  ms for  $0^\circ$ ,  $423 \pm 104$  ms for  $90^\circ$ ,  $430 \pm 84$  ms for  $180^\circ$ , and  $421 \pm 77$  ms for  $270^\circ$ . No significant differences were

evident. The results are shown in Fig. 5.

#### 5. P300 amplitude by presented orientation

With tooth task, P300 amplitude was  $11.9 \pm 4.6 \mu\text{V}$  for  $0^\circ$ ,  $8.9 \pm 4.6 \mu\text{V}$  for  $90^\circ$ ,  $7.1 \pm 4.3 \mu\text{V}$  for  $180^\circ$ , and  $9.3 \pm 5.2 \mu\text{V}$  for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$ , between  $0^\circ$  and  $180^\circ$ , between  $0^\circ$  and  $270^\circ$ , between  $90^\circ$  and  $180^\circ$ , and between  $180^\circ$  and  $270^\circ$ .

With script task, P300 amplitude was  $16.2 \pm 6.1 \mu\text{V}$  for  $0^\circ$ ,  $12.3 \pm 4.0 \mu\text{V}$  for  $90^\circ$ ,  $8.5 \pm 3.9 \mu\text{V}$  for  $180^\circ$ , and  $13.0 \pm 4.8 \mu\text{V}$  for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$ , between  $0^\circ$  and  $180^\circ$ , between  $0^\circ$  and  $270^\circ$ , between  $90^\circ$  and  $180^\circ$ , and between  $180^\circ$  and  $270^\circ$ .

With hand task, P300 amplitude was  $13.8 \pm 6.5 \mu\text{V}$  for  $0^\circ$ ,  $10.3 \pm 5.8 \mu\text{V}$  for  $90^\circ$ ,  $9.7 \pm 4.7 \mu\text{V}$  for  $180^\circ$ , and  $11.7 \pm 5.4 \mu\text{V}$  for  $270^\circ$ . Significant differences were recognized between  $0^\circ$  and  $90^\circ$  and between  $0^\circ$  and  $180^\circ$ . The results are shown in Fig. 6.

#### 6. Features of the waveform

Script and hand tasks showed typical P300 waveforms with a peak of about  $12 \mu\text{V}$  at  $0^\circ$ . However, tooth task displayed a relatively flat waveform regardless of presented orientation. The results are shown in Fig. 7.

#### 7. Correlations of waveform components

Dividing the P300 waveform into from stimulus onset to 300 ms and from 300 ms to 600 ms, each of the two portions of the waveform was examined with

respect to correlation between presented orientations.

The correlation coefficients between presented orientations in the three tasks are shown in Table 3. There were strong correlations between all presented orientations in the three tasks for the onset to 300 ms portion. In addition, for the 300 to 600 ms portion, there were strong correlations between 0° and 90° in tooth task, between 90° and 270° in script task, and between 0° and 180°, 0° and 270°, and 180° and 270° in hand task.

## **Discussion**

To recognize an object, humans can use two forms of processing: data-driven processing and conceptually driven processing. Data-driven processing is a bottom-up form of information processing affected by stimulus characteristics such as profile, lines, and margins of the object itself. Conceptually driven processing is a top-down form of information processing affected by knowledge about daily life stored in the memory. The beginning of pattern recognition involves extracting external features from a certain object space, and extracting further feature parameter and then conducting feature analysis. Moreover, pattern recognition is said to be influenced by concepts such as past experience, rather than by the input signal alone (2,3).

In the present study, the identification of tooth type from basic visual information is processed through the visual association area in the primary visual cortex and the shape is recognized. The concept of a tooth is then generated

according to the process of general cognition and compared with knowledge stored in high-order association areas, and a semantic interpretation of the visual information is produced. As a result, tooth identification was considered difficult according to the subjective VAS scale. All tasks showed a correct answer rate of over 90%, with no differences by category. In terms of presented orientations of tasks, no differences were seen with tooth or hand task, but script task showed a significant difference between 0° and 180°, with correct answer rates of 100% at 0° and 96% at 180°. Therefore, the difficulties of the tasks were similar.

Reaction time represents the sum of both the time to push the button after making a positive determination and the processing time involved in the comparison and evaluation of the stimulus in the brain when performing the task. (20). Reaction time has been widely used in cognition experiments as a conventional measurement item (21). Recognition of presented orientation is considered to involve mental rotation of the image by the brain. For two figures presented with different orientations and recognized as the same figure following mental rotation, Shepard and Metzler (10) rotated the object imagined in the brain, performed pattern recognition, and reported that rotation takes a fixed amount of time. Cooper et al. (11) reported that the time required is proportional to the difference between the orientation angles of the presented stimulus. In Japan, Miyatani et al. (15) reported on counterclockwise rotation of a mental image of katakana. That study showed that reaction time was longest at about 160-200° and became shorter at around 270-320°. In the present study, as a tendency common to all tasks, reaction time was shortest at 0°, increased with orientation angle to 180°, and then decreased at 270°. From these results, all tasks appeared

to be judged using mental rotation.

On the other hand, because the time requirement also includes that for the reaction-processing system due to the need to press a button, reaction time did not directly reflect information processing in the brain. The waveform components of ERP examined using P300 thus reflect internal information-processing activities. P300 is affected by task, reflecting cognitive function. P300 latency represents a stimulus evaluation time, while P300 amplitude reflects attention allocation, context updating of memory, and processing capacity required for cognitive process in the brain. In addition, as a task becomes more difficult, P300 latency is expected to increase and P300 amplitude is expected to decrease (22,23).

P300 latency across different presented orientations and tasks showed a value of 400-460 ms, which is relatively consistent. This means that evaluation time is relatively constant regardless of stimulus presentation. P300 amplitude was maximal at 0°, decreased with increasing orientation angle to a minimum at 180°, and increased again at 270°. All tasks showed the same result. At the 0° orientation, all tasks may be handled with a relatively small amount of resources in the processing of perception. The 180° orientation required the greatest use of cerebral resources. In contrast, the 0° orientation tasks present an image with the buccal side uppermost as described in dental textbooks, script in the orientation familiar from everyday life, and the state of the palm as seen by the individual for their own hand. Such images would be present in the brain as typical forms (templates), and would be recognized by matching with retinal images.

We have discussed these issues from a macro perspective according to the temporal window and shape of the entire waveform, not from the perspective of



peak identification procedures. From the stimulus onset to 300 ms portion of the ERP waveform, we can conclude that almost the same brain processes are performed at an early stage regardless of the image. This is because ERP does not show waveform changes with differences in presented orientation, showing strong correlations between all orientations. In other words, it has been suggested that cognition level required to recognize the basic component of tooth, script, and hand images was the same across tasks. However, differences were seen in the P300 component after 300 ms. Script and hand tasks showed a typical waveforms at 0°, whereas tooth task showed a distinctly different P300 waveform at 0°. In the script and hand cases, pattern recognition is carried out effectively by bottom-up and top-down processing, since these representations are extremely familiar from everyday life. In the tooth case, it was suggested that activity of the brain by top-down processing of the concerned concepts cannot be performed effectively, since empirical knowledge and handling processes were insufficient. A similar trend was observed in presented orientations other than 0°.

In the case of script and hand tasks, the 0° orientation represents the template for typical pattern recognition, and information processing can perform discrimination judgment, including the use of acquired knowledge in higher-order association areas. In the case of tooth discrimination, the results of this study suggest that only basic information processing is possible, regardless of presented orientation.

In short, for knowledge novices, it was suggested that although it is possible for them to recognize basic components, by a bottom-up process, they cannot use a top-down process well due to their lack of experience.

## Conclusion

To clarify the cognitive information-processing processes of students who have mastered textbook knowledge about teeth, we studied ERP and reached the following conclusions:

1. The correct answer rate was high in all tasks, at 90% or more, and no differences in tooth differentiation were seen by presented orientation.
2. According to subjective evaluations of difficulty, tooth task was rated as difficult, in particular showing a significant difference compared with script task.
3. With all tasks, reaction time increased with the increase in presented orientation until 180°, and then decreased at 270°. This result suggested that tasks were performed with mental rotation.
4. P300 latency was almost the same for all tasks. As a result, the brain appears to be performing the same processing, regardless of presented orientation.
5. With all tasks, P300 amplitude decreased with increasing presented orientation to reach a minimum at 180° and then increased again at 270°. Processing capacity required within the brain thus differed by presented orientation.
6. A tendency was seen for script and hand tasks to be easy at 0°, whereas tooth discrimination remained difficult regardless of presented orientation.
7. With all tasks, the waveform portions from stimulus onset to 300 ms showed

strong correlations between presented orientations. All tasks thus seemed to show the same fundamental information processing of profile, lines, and margins.

Summarizing, discrimination of script characters and hands involves both top-down and bottom-up processing. In contrast, discrimination of a tooth involves a significant predominance of bottom-up processing.

Regarding dental students novices who have mastered textbook knowledge of teeth, this study has found that knowledge novices depend heavily on bottom-up processing of the physical characteristics because of their lack of experience, rather than performing bottom-up processing and top-down processing equally.

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## **Table and Figure**





**Table 1. VAS and Correct answer rate of 3 tasks (tooth, script, and hand)**

	Correct answer rate (%)	VAS (evaluation value)
tooth	95 (5)	56 (29)
script	98 (2)	21 (23)
hand	98 (2)	38 (30)

n=19, Mean(SD), \*Mann–Whitney U test (p<0.017)



Table 2. Correct answers rate in 3 tasks (tooth, script, and hand) for each presented orientation

	tooth (%)	script (%)	hand (%)
0°	97 (5)	100 (1)	99 (2)
90°	93 (10)	99 (2)	95 (8)
180°	96 (5)	96 (5)	99 (2)
270°	95 (6)	99 (4)	99 (1)

n=19, Mean(SD), \*Wilcoxon signed-rank test (p<0.008)

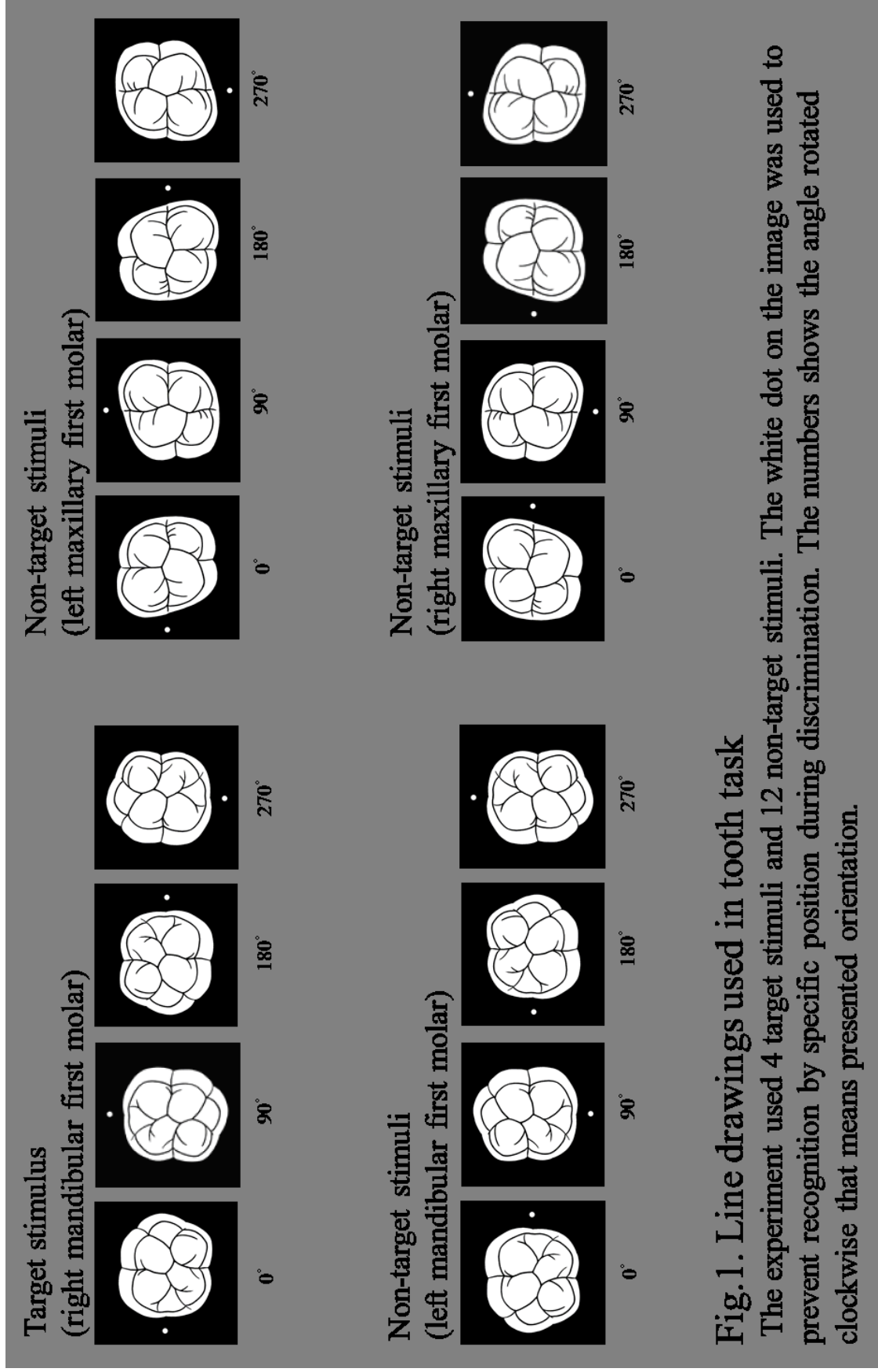


Table 3. Correlation coefficient between presented orientation in 3 tasks (tooth, script, and hand)

		tooth 0-300 ms			tooth 300-600 ms				
		0°	90°	180°	270°	0°	90°	180°	270°
0°		—	—	—	—	0°	—	—	—
90°		0.712*	—	—	—	90°	0.843*	—	—
180°		0.806*	0.852*	—	—	180°	0.371	0.269	—
270°		0.817*	0.856*	0.793*	—	270°	0.615*	0.326	0.253
		script 0-300 ms			script 300-600 ms				
		0°	90°	180°	270°	0°	90°	180°	270°
0°		—	—	—	—	0°	—	—	—
90°		0.760*	—	—	—	90°	0.317	—	—
180°		0.733*	0.829*	—	—	180°	0.164	0.341	—
270°		0.711*	0.867*	0.948*	—	270°	0.328	0.924*	0.492*
		hand 0-300 ms			hand 300-600 ms				
		0°	90°	180°	270°	0°	90°	180°	270°
0°		—	—	—	—	0°	—	—	—
90°		0.787*	—	—	—	90°	0.266	—	—
180°		0.718*	0.870*	—	—	180°	0.831*	0.577*	—
270°		0.738*	0.876*	0.87*	—	270°	0.846*	0.617*	0.920*

n=19, \*Spearman's rank correlation ( $p < 0.05$ )





**Fig. 1. Line drawings used in tooth task**

The experiment used 4 target stimuli and 12 non-target stimuli. The white dot on the image was used to prevent recognition by specific position during discrimination. The numbers show the angle rotated clockwise that means presented orientation.





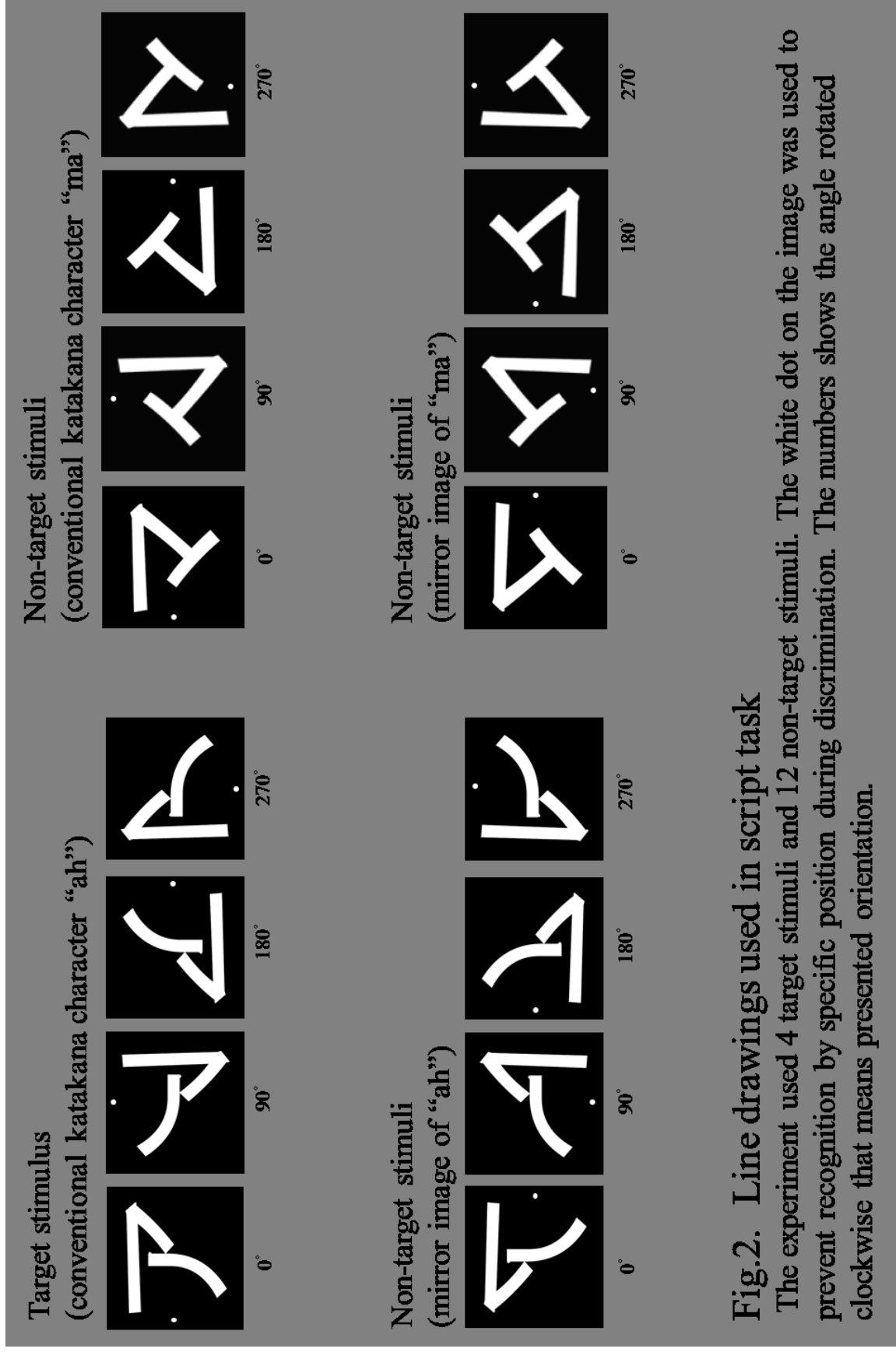
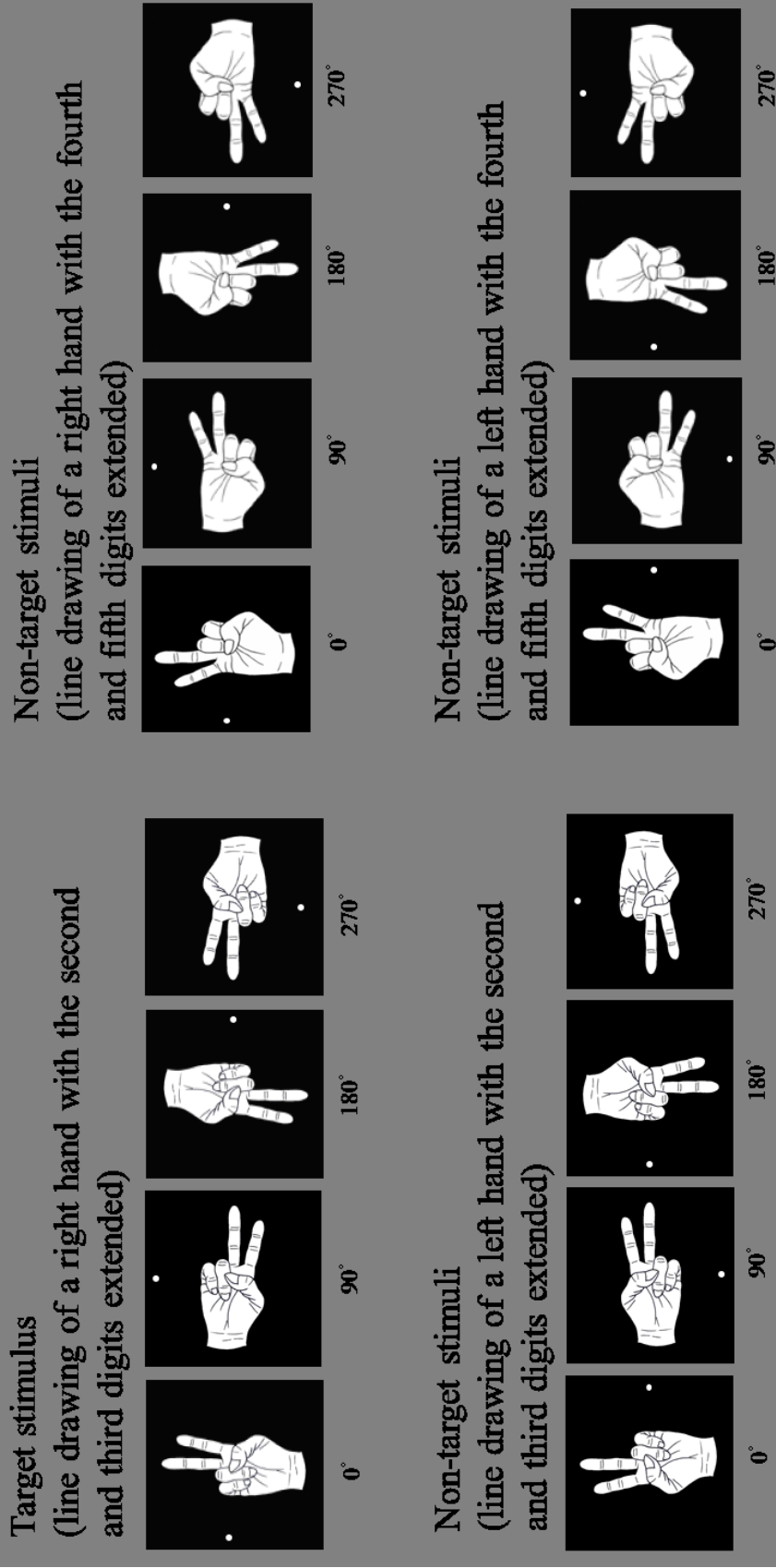


Fig.2. Line drawings used in script task

The experiment used 4 target stimuli and 12 non-target stimuli. The white dot on the image was used to prevent recognition by specific position during discrimination. The numbers show the angle rotated clockwise that means presented orientation.





**Fig.3. Line drawings used in hand task**

The experiment used 4 target stimuli and 12 non-target stimuli. The white dot on the image was used to prevent recognition by specific position during discrimination. The numbers show the angle rotated clockwise that means presented orientation.



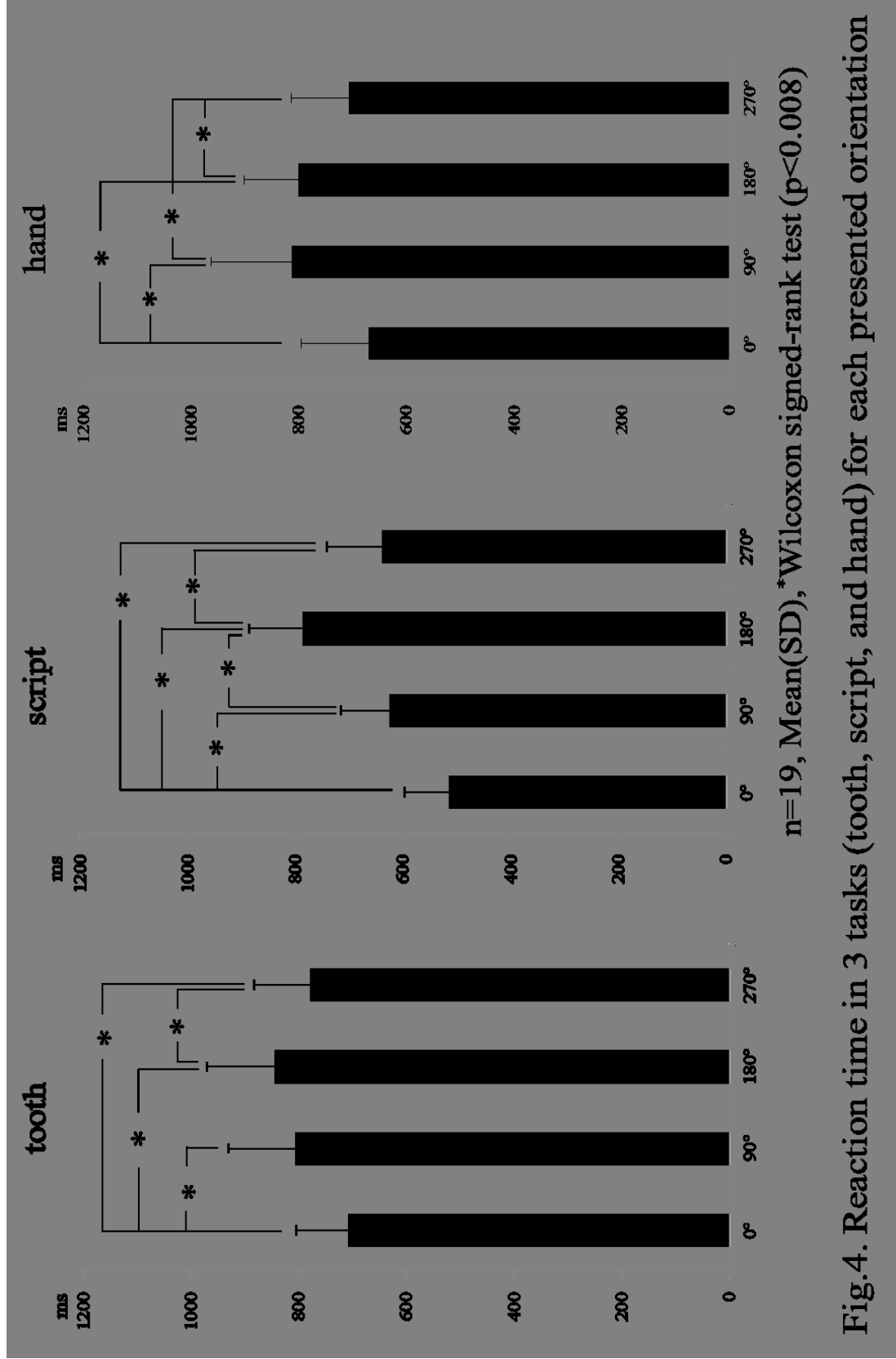


Fig.4. Reaction time in 3 tasks (tooth, script, and hand) for each presented orientation



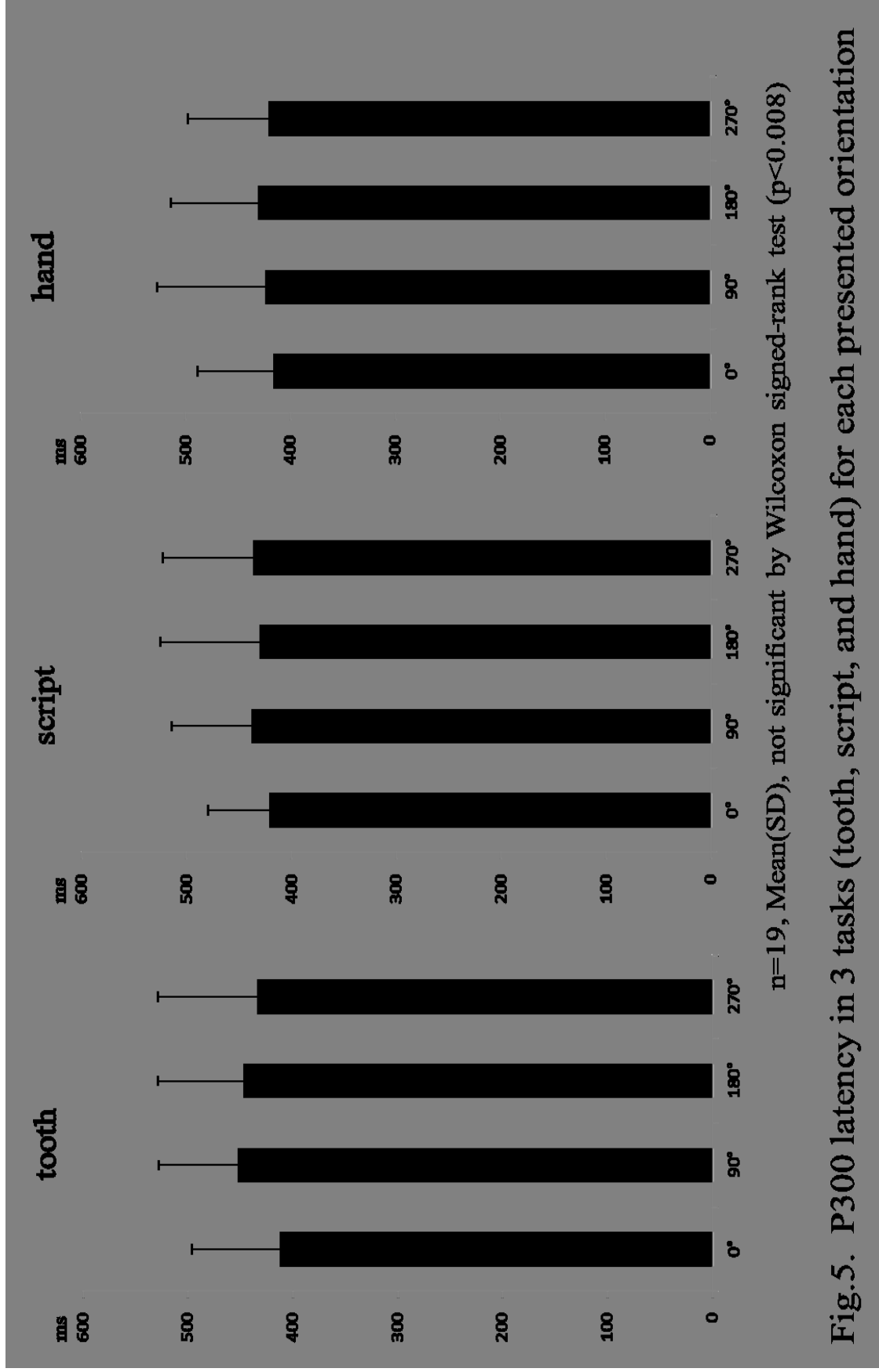


Fig.5. P300 latency in 3 tasks (tooth, script, and hand) for each presented orientation





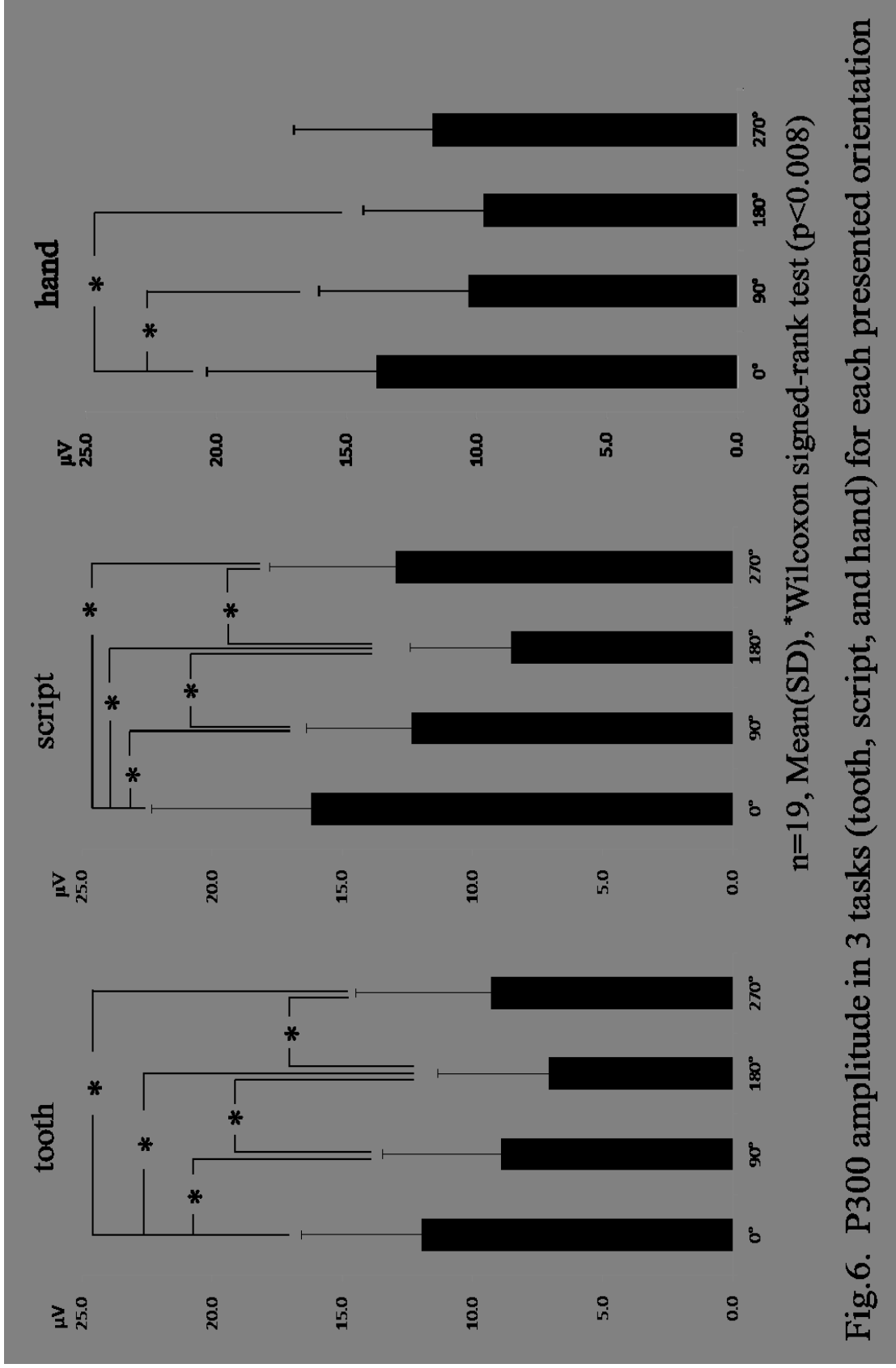
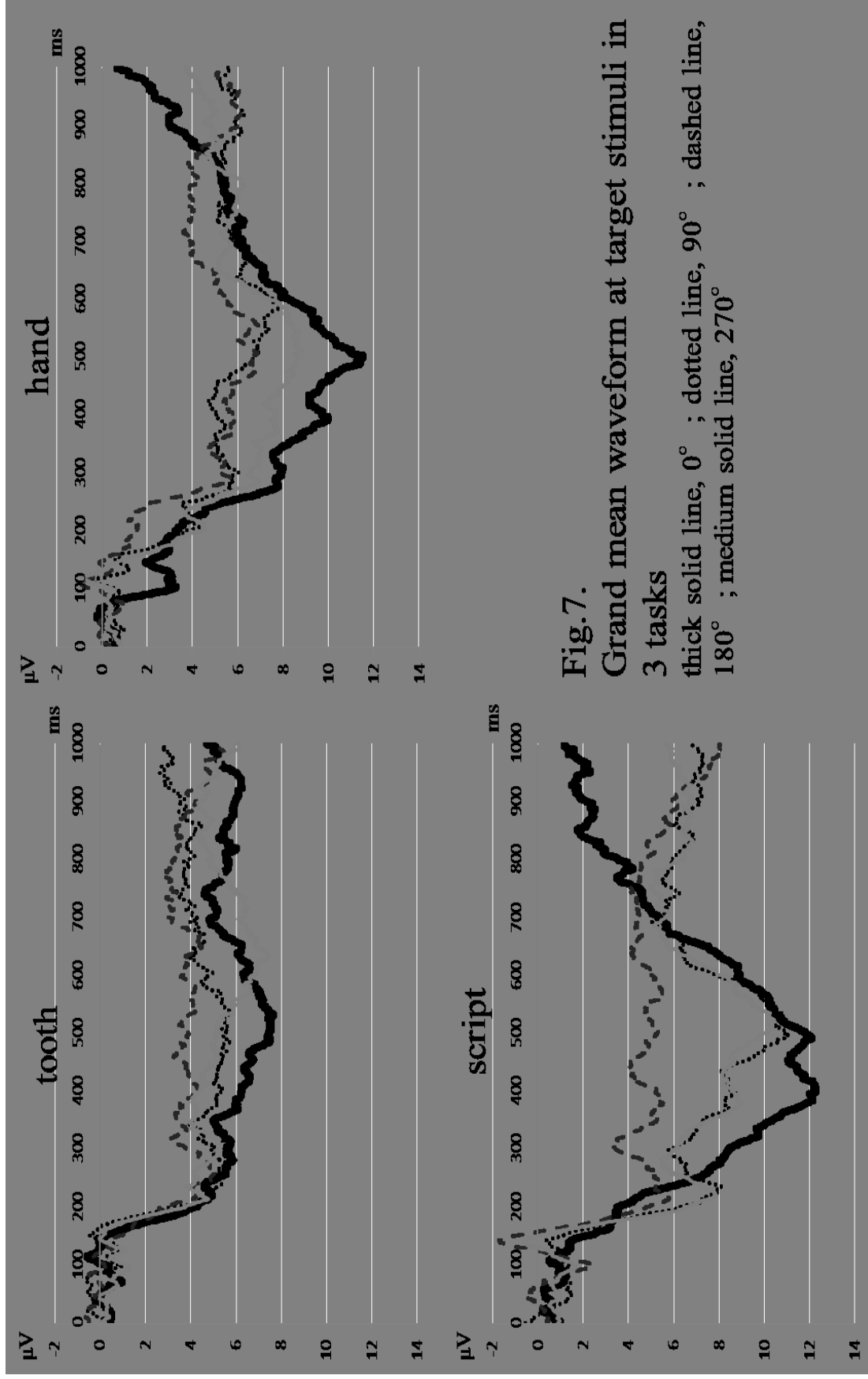


Fig.6. P300 amplitude in 3 tasks (tooth, script, and hand) for each presented orientation





**Fig.7.**  
**Grand mean waveform at target stimuli in**  
**3 tasks**  
**thick solid line,  $0^\circ$  ; dotted line,  $90^\circ$  ; dashed line,**  
 **$180^\circ$  ; medium solid line,  $270^\circ$**

