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Effect of sports experience on changes associated with maintaining neck flexion in distribution of pro-saccade reaction time under gap task

Kenji Kunita

k-kunita@ts.siu.ac.jp

Sapporo International University

Katsuo Fujiwara

Kanazawa Gakuin University

Chie Yaguchi

Japan Health Care College

Fumiaki Sato

Sapporo International University

Research Article

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Abstract

Background

The present study investigated the effect of sports experience on changes with maintaining the neck flexion in the distribution of pro-saccade reaction time under gap task.

Methods

Participants comprised 15 members from each of the basketball club group (Group BB), table tennis club group (Group TT), and a non-sporting control group (Group C). Pro-saccade overlap and gap reaction tasks were carried out while maintaining neck rest and flexion positions. Reaction times were divided into 10-ms bandwidths for each neck position and saccadic task, and the histogram of relative frequencies for all trials was created. The median bandwidth at which the earliest peak appeared was calculated. Furthermore, the bandwidth showing the earliest peak in the histogram for the gap task at the neck rest position was defined as the criterion bandwidth (0-ms), and the distribution of relative frequencies was recalculated.

Results

The median bandwidth at which the earliest peak appeared was significantly shorter in the neck flexion position than in the neck rest position in both Groups BB and TT for all tasks, but no significant change was observed in Group C. In Group BB, the distribution of reaction times under the gap task showed a significant increase in the early component of the bimodal distribution and a significant decrease in the late component while maintaining neck flexion. Group TT showed a significant increase in the early unimodal distribution while maintaining neck flexion.

Conclusions

The present study indicated that sports experience leads to an earlier distribution of pro-saccade reaction times under the gap task, associated with the neck flexion position. Furthermore, the early positioning of the distribution differed depending on the sport experienced.

Background

The human head weighs approximately 8% of total body weight. This imposes limits on the gaze accompanying larger and more rapid shifts, by using head movements alone [1]. The visual resolution of the retina is highest at the central fovea and decreases exponentially with increasing distance from the fovea [2]. Saccadic eye movement (saccade) that quickly and precisely matches the fovea to the visual

object accompanying an abrupt shift is important for perceiving the object in a sports scenario [3–5]. Saccades toward the appearing visual object are called pro-saccades.

Functions associated with pro-saccade, controlled via supraspinal pathways, are detection of the visual target, identification of the target position, saccade preparation, disengagement of fixation, and saccade generation [6, 7]. Disengagement of fixation has been investigated using overlap and gap tasks, in which the timing between switch-off of the central fixation point and lighting of the visual target is manipulated [8–10]. The overlap task is one in which the peripheral visual target emerges before or just after switch-off of the fixation point. Under the overlap task, intentional disengagement of fixation is important for saccade generation, which is particularly related to the frontal eye fields in the higher saccade system. In relation to the involvement of the higher saccade system associated with intentional disengagement, the pro-saccade reaction time under the overlap task shows a unimodal distribution with the peak ranging from 180 to 200-ms [10, 11]. On the other hand, the gap task is one in which the central fixation point is turned off some time (mainly 200-ms) before emergence of the peripheral visual target [10, 12]. Under this task, the higher saccade system is less involved; instead, the subcortical pathways and primary visual cortex associated with the reflexive disengagement of fixation are more prominent compared with the overlap task. Under the gap task, pro-saccade reaction time shows a bimodal distribution, with the peak ranging from 100 to 120-ms associated with reflexive disengagement of fixation (first peak), in addition to the above-mentioned peak ranging from 180 to 200-ms associated with the intensive disengagement of fixation, similar to the situation in the overlap task (second peak) [10, 13].

Previous studies have suggested that substantial individual variation exists in the distribution of pro-saccade reaction time under the gap task, which shows the above-mentioned bimodal distribution and unimodal distribution with the peak ranging from 100 to 120-ms [10, 13]. The individual variation has been investigated from the perspective of learning and training related to the disengagement function of fixation [10–12]. Sports experience is regarded as one form of learning and training. In the previous study, to investigate the influence of sports experience on that distribution at the neck rest position, it was noted that the functions of disengagement of fixation differ markedly between basketball and table tennis [14]. For basketball, attention to the whole visual field and/or parallel attention to various objects including the ball and players in the peripheral visual field are important [15–18]. In particular, intended attention to the visual object with inhibition of reflexive disengagement of fixation to fakes and feints is important. When performing saccade to the appearing visual object in basketball, disengagement of fixation would be intensive. In the previous study, it was confirmed that for the basketball group (Group BB), pro-saccade reaction times under the gap task show bimodal distribution, consisting of a peak ranging from 100 to 120-ms associated with reflexive disengagement of fixation, in addition to the peak ranging from 180 to 200-ms, associated with intensive disengagement of fixation [14]. On the other hand, in table tennis, the distance between players is only about 3 m and the playing time in which to return the fast-moving ball is markedly short compared to other ball sports [3, 19]. In table tennis, reflexive disengagement of fixation is therefore particularly important. In the previous study, it was confirmed for the table tennis group (Group TT), pro-saccade reaction times under the gap task show

unimodal distribution with the peak ranging from 100 to 120-ms, associated with reflexive disengagement of fixation [14].

When rapidly perceiving a visual object in a sports scenario, the basic dynamic posture, a posture of readiness associated with starting body movement, is frequently maintained [20]. It was previously found that pro-saccade reaction time shortened with maintenance of the neck flexion position, representing part of the dynamic posture [21–24], and found a series of findings associated with this shortening as follows. The physiological factor generating the decrease in pro-saccade reaction time with maintenance of neck flexion position was considered to be an ascending brain activation system, originating in the brainstem reticular formation and involving the thalamus, hypothalamus, and basal forebrain, in tandem with increases in muscle afferent information[25–27], and/or a descending brain activation system originating in the cerebral cortex [21, 28]. However, the shortening in pro-saccade reaction time associated with maintaining neck flexion position was not observed in all subjects. Previous findings suggested that sports experience and training were important for shortening [4, 23]. However, the shortening in pro-saccade reaction time associated with neck flexion position was investigated using the overlap task, and few studies using the gap task have been reported.

The present study investigated the effects of sports experience on changes while maintaining neck flexion position in the distribution of pro-saccade reaction times under the gap task. In basketball, where rapid gaze is required (such as in one-on-one defense), players focus on the opponent's head rather than on peripheral areas of the court [29]. Under these conditions, early release of fixation and initiation of eye movements are crucial. We presumed that in Group BB, the brain activation effect while maintaining neck flexion position selectively and significantly affects the reflexive release of fixation. We also presumed that in Group TT, the activation effect significantly affects the reflexive release of fixation. In addition, significant effects of neck flexion position were considered unlikely to be present in a non-sporting control group (Group C).

The working hypothesis was therefore as follows: the shortening associated with maintaining neck flexion position would be found in only Groups BB and TT in the distribution of pro-saccade reaction time under the gap task. In Group BB, the distribution of reaction times would show a significant increase in the early component of the bimodal distribution and a significant decrease in the late component while neck flexion position was maintained. In Group TT, a significant increase in the early unimodal distribution would be observed.

Methods

Subjects

Subjects were students belonging to our university, divided into three groups. Subjects in Group BB had belonged to the basketball club for ≥4 years (15 participants; mean age, 20.8 years). Subjects in Group TT had belonged to the table tennis club for ≥4 years (15 participants; mean age, 21.2 years). Subjects in

Group C had never belonged to any sports clubs between elementary school and university (15 participants; mean age, 20.4 years). No participants had any history of neurological impairment. In accordance with the Declaration of Helsinki, all participants provided informed consent after receiving an explanation of the experimental protocol, which was approved by the ethics committee belonging to our university (approval no. 20499004).

Apparatus and data recording

The experimental setup is shown in Fig. 1. The participant sat on a steel-frame chair with the back resting against a vertical wall, and the trunk was secured by a cotton band to prevent anteroposterior movement. The knees were kept flexed at approximately 90° and the feet rested on a low table. The neck flexion angle was defined as the rotational angle of the tragus around the acromion in the sagittal plane with the starting position (0°) as neck rest position. We determined 80% of maximal neck flexion angle (neck flexion position) for each participant using a custom-made angular detector with the center point set at the acromion, while regulating the distance between the acromion and tragus. Angle of head inclination was determined as the angle between the auriculo-infraorbital line and the gravitational line, and was maintained at the same angle as the sitting posture to maintain constant sensory inputs from the vestibular organs. An angle detector using the pendulum principle was attached to the temple to confirm this angle. A chin stand was used to support the head and allow maximal relaxation of the neck extensor muscles.

A visual stimulator (LPK-200; Electro Design) was used to induce saccadic eye movements. Light-emitting diodes (LEDs) located at the central fixation point and at the targets were illuminated for time periods set by the stimulator and a functional generator (WF1966; NF corporation). LEDs were placed at the height of the nose root, and the distance between the LED at the central fixation point and the nose root was set at 50 cm. Based on Braun & Breitmeyer [30], the two lateral targets were located at 4° to the left and right of the central fixation point, and were presented with equal probability at random.

Horizontal eye movement and blink were measured using electrooculography (EOG). Horizontal EOG was recorded from surface electrodes at the outer canthus of each eye, and vertical EOG was recorded from electrodes above and below the left eye. A ground electrode was placed at the center of the forehead. Electrode-input impedance was reduced to < 10 kΩ. The signal from the electrodes was amplified (×2,000) using a DC amplifier (AN-601G; Nihon Kohden). To obtain stable EOG traces, recording began at least 20-min after the placement of electrodes. Surface electrodes with bipolar derivation were used to monitor and record surface electromyography (EMG) for bilateral upper trapezius muscles. Inter-electrode distance was at about 3-cm. A ground electrode was placed at the spinous process of the C7 vertebra. Electrode impedances were reduced to < 5 kΩ. Signals from these electrodes for the trapezius were amplified (×2,000) and band-pass filtered (5–500 Hz), using an EMG amplifier (MA1000; DIGITEX).

EOG and visual stimulus data were sent to a computer (Dimension E521; Dell) via an A/D converter at 1,000 Hz with 16-bit resolution. EMG data were sent to an oscilloscope (DS-6612; Iwatsu) to monitor

activation.

Procedure

Participants performed the pro-saccade overlap or gap tasks while maintaining an neck rest or neck flexion position (Fig. 2). Initially, to familiarize the participant with the saccade task, 20 practice trials were performed under each task. In the neck rest position condition, prior to beginning the task, contraction and relaxation of the trapezius muscles were alternated several times and the participant took deep breaths to relax the muscles. The experimenter verbally instructed the participant to relax the trapezius muscle, which was monitored by EMG. LED illumination was then started. Under the neck flexion position condition, the participant first performed neck flexion within approximately 3-s, maintained this position for 2-s, then started each trial. In the overlap task, the central fixation point was illuminated for a random duration ranging from 1 to 3-s, then the fixation point was turned off. Just after switching the fixation point off, one of the peripheral targets was illuminated for a duration of 1-s. The visual stimulus under the gap task was almost the same as that under the overlap task, but only the temporal gap between switching off the central fixation point and onset of the peripheral target differed between those tasks. Gap duration in the gap task was set at 200-ms. Each saccade task was repeated as eight sets of 25 trials; that is, 200 trials were performed in each task. Rest periods of 3-min and 5-min were provided between sets and between postural conditions, respectively. The order of conditions (task × postural condition) was counterbalanced across participants to consider the potential effects of fatigue and sequential learning.

Data analysis

Analyses of visual stimulus and pro-saccade were performed using BIMUTAS-II software (Kissei Comtec). Pro-saccade reaction time was defined as the latency between onset of target movement and beginning of eye movement (Fig. 3). Onset of eye movement was determined by visual inspection of EOG displacement that was easily discernible from baseline. Referring to Fischer and Weber [10] and Braun and Breitmeyer [30], histograms of relative frequencies for all trails were constructed using a bandwidth of 10-ms. Mean and standard deviation (SD) of the median bandwidth showing the earliest peak in the histogram were calculated for each group, according to postural condition and saccadic task. Thereafter, for each participant, the bandwidth showing the earliest peak under the gap task in the neck rest position was defined as the criterion bandwidth (0-ms bandwidth). Based on this criterion bandwidth (0-ms bandwidth), mean and SD of relative frequencies were recalculated for every 10-ms of bandwidth, for the overlap and gap tasks, according to postural condition and saccadic task, for each group.

Statistical analysis

The Silverman test using the kernel density method was used to test the distribution of pro-saccade reaction time for bimodal distribution or unimodal distribution [31, 32]. Two-way analysis of variance (ANOVA) was used to assess the significance of effects of group and postural condition on median peak

bandwidth in histograms of relative freqiencies of pro-saccade reaction time, for each saccadic task. When a significant interaction between these effects or a main effect of group was shown, post-hoc multiple comparison analysis using Tukey's honestly significant difference (HSD) was performed to assess differences among groups. Furthermore, a paired t-test was performed to compare median mean values between posture conditions for all groups. In the histograms for each relative freqiencies, one-way repeated-measures ANOVA was performed to examine the effect of difference for each group, neck condition, and task. If a main effect was observed among bandwidths, a multiple comparison test using the Tukey's HSD method was performed. Furthermore, a paired t-test was performed for each group and saccade condition to examine significant differences between posture conditions in the same bandwidth. The alpha level was set at $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics version 22 (IBM Japan) and the program on the database of the Paleontological Society of Japan.

Results

Figure 4 shows a representative histogram of relative frequencies for pro-saccade reaction time (A: unimodal distribution under the overlap task; B: bimodal distribution under the gap task). Table 1 shows the numbers of participants demonstrating bimodal distribution and unimodal distribution of pro-saccade reaction time in each group. Under the overlap task, the distribution of pro-saccade reaction time was unimodal for all participants in either postural condition. Under the gap task with the neck rest position, bimodal distribution was seen for 8 of 15 participants in Group BB and for 2 of 15 participants in Group C (*ps* < 0.05). The distribution in Group TT was unimodal for all 15 participants. Under the gap task with neck flexion position, the distribution was unimodal for all participants in each group.

Figure 5 shows mean and SD of median bandwidth showing the earliest peak in the histogram of relative frequencies for each group. A significant interaction between postural condition and group was found in the mean value for both saccadic tasks (gap task $F_{2,42} = 7.11$, $p < 0.01$; overlap task $F_{2,42} = 3.84$, $p < 0.05$). In the neck rest position, no significant group difference in mean value was found for both saccadic tasks. In Groups BB and TT, for both saccadic tasks, the mean value in the neck flexion position was shorter than that in the neck rest position (Group BB: gap task $p < 0.01$, overlap task $p < 0.001$; Group TT: gap task $p < 0.01$, overlap task $p < 0.01$). On the other hand, in Group C, mean values did not differ significantly between the postural conditions under either saccadic task.

Figures 6–8 show mean and SD of relative frequencies, based on the criterion bandwidth (0-ms bandwidth) in each group, for both saccadic tasks. In Group BB, under the gap task with neck rest position, no significant difference was found at + 40-ms bandwidth in comparison to 0-ms bandwidth; namely, a bimodal distribution was shown. The nearest adjacent bandwidths showing a significant reduction compared to 0-ms bandwidth (first peak) were − 10-ms and + 10-ms bandwidths (*ps* < 0.001). Significant reduction was found at + 30-ms and + 50-ms bandwidths in contrast to + 40-ms bandwidth (second peak: +30-ms, $p < 0.001$; +50-ms, $p < 0.05$). Under the overlap task with neck rest position, the nearest adjacent bandwidths showing a significant reduction compared to + 50-ms bandwidth were 0-

ms and + 80-ms bandwidths (0-ms, $p < 0.001$; + 80-ms, $p < 0.05$). Under the gap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to 0-ms bandwidth were − 20-ms and + 10-ms bandwidths (*ps* < 0.001). Under the overlap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to + 40-ms bandwidth were + 10-ms and + 80-ms bandwidths (*ps* < 0.001).

In Group TT, under the gap task with neck rest position, the nearest adjacent bandwidths showing significant reduction compared to 0-ms bandwidth were − 10-ms and + 10-ms bandwidths (*ps* < 0.001). Under the overlap task at neck rest position, the nearest adjacent bandwidths showing significant reduction compared to + 40-ms bandwidth were 0-ms and + 70-ms bandwidths (0-ms, $p < 0.001$; +70-ms, *ps* < 0.01). Under the gap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to 0-ms bandwidth were − 20-ms and + 10-ms (*ps* < 0.001). Under the overlap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to + 20-ms bandwidth were 0-ms and + 60-ms bandwidths (*ps* < 0.001).

In Group C, under the gap task with neck rest position, the nearest adjacent bandwidths showing significant reduction compared to 0-ms bandwidth were − 10-ms and + 10-ms bandwidths (*ps* < 0.001). Under the overlap task with neck rest position, the nearest adjacent bandwidths showing significant reduction compared to + 30-ms bandwidths were 0-ms and + 80-ms bandwidths (0-ms, $p < 0.05$; +80-ms, $p < 0.01$). Under the gap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to + 50-ms bandwidth were − 10-ms and + 20-ms (*ps* < 0.001). Under the overlap task with neck flexion position, the nearest adjacent bandwidths showing significant reduction compared to + 30-ms bandwidth were + 10-ms and + 50-ms bandwidths (*ps* < 0.05).

The distribution of pro-saccade reaction time was compared between both neck conditions for Groups BB and TT, in which the median bandwidths showing the earliest peaks in the histogram of relative frequencies were significantly shortened by maintaining the neck flexion position. In the gap task for Group BB, a significant increase in relative frequencies with neck flexion position was found in the − 50-ms, -30-ms, -20-ms, -10-ms, and 0-ms bands (*ts* ≥ 2.68, *ps* < 0.05), and a significant reduction with neck flexion position was found in the + 40-ms, + 50-ms, + 60-ms, + 70-ms, + 80-ms, + 100-ms, and + 110-ms bandwidths (*ts* ≥ 2.17, *ps* < 0.05; Fig. 9). In the overlap task, a significant increase in relative frequencies with neck flexion position was found in the + 10-ms and + 40-ms bandwidths (*ts* ≥ 2.63, *ps* < 0.05), and a significant reduction with neck flexion position was found in the + 100-ms, + 110-ms, + 120-ms, + 130-ms, and + 150-ms bandwidths (*ts* ≥ 2.79, *ps* < 0.05). In the gap task for Group TT, a significant increase in relative frequencies with the neck flexion position was found in the − 30-ms and − 20-ms bandwidths (*ts* ≥ 2.16, *ps* < 0.05), and significant reductions with neck flexion position were found in the + 30 ms and + 50 ms bandwidths (*ts* ≥ 2.82, *ps* < 0.05; Fig. 10). In the overlap task, a significant increase in relative frequencies with the neck flexion position was found in the + 10-ms bandwidth ($t = 2.48$, $p < 0.05$), and a significant reduction with the neck flexion position was found in the + 80-ms bandwidth ($t = 2.81$, $p < 0.05$).

Discussion

The distribution of pro-saccade reaction time under the overlap task was unimodal in each postural condition for all groups. Considering the mean median bandwidth in which the earliest peak in relative frequencies of pro-saccade reaction time appeared, this distribution was suggested to be related to information processing in higher brain regions associated with intentional release of visual fixation. Further, when the neck flexion position was maintained, Groups BB and TT, who had athletic experience, showed a shortened peak value. Conversely, no significant difference in peak values was observed between posture conditions in Group C. This shortening of reaction times with maintaining the neck flexion position in the experienced athletic group, under the overlap-task, supports the previous study [4].

Previous studies have reported that under the gap task, subcortical and primary visual cortex regions associated with reflexive fixation release are more involved [10]. The distribution of pro-saccade reaction time under this condition has been reported to be bimodal, with a peak ranging from 180 to 200-ms, associated with intentional fixation release (the same as under the overlap task), and a peak ranging from 100 to 120-ms, associated with reflexive fixation release [10, 13]. Under the gap task with neck rest position, Group BB showed a clear bimodal distribution, while Group TT showed an early unimodal distribution. The results in this study was consistent with the previous research [14].

An important finding of this study was that the effect of the sports experience was found in the changes while maintaining the neck flexion position, in the distribution of pro-saccade reaction time under the gap task. In Group BB, the distribution showed a significant increase in the bimodal early component and a significant decrease in the late component, while maintaining the neck flexion position. In Group TT, the early component became even earlier. As mentioned in the Introduction, the mechanism of brain activation associated with maintaining the neck flexion position is ascending activation originating from the reticular formation of the brainstem, associated with increased sensory information from the neck muscles and/or descending activation from the cerebral cortex associated with activity of the neck muscles [21, 25–28]. The results of this study suggested that in Group BB, brain activation associated with maintaining the neck flexion position enhances the ability to reflexively release visual fixation and reduces the ability to intentionally release visual fixation. We also suggested that in Group BB, brain activation while maintaining the neck flexion position significantly enhanced the function of the subcortical and primary visual cortex, and reduces the function of the frontal eye field. For Group TT, they suggested that the activation effect markedly enhances the ability to reflexively release visual fixation. Further, we also suggested that in Group TT, the activation effect furthermore significantly affects the functions of the subcortical and primary visual cortex.

Conclusion

The present results indicated that the effect of the sports experience was found on changes associated with maintaining the neck flexion position in the distribution of pro-saccade reaction time under the gap task. In Group BB, the distribution showed a significant increase in the bimodal early component and a

significant decrease in the late component, while maintaining the neck flexion position. In Group TT, the early component became even earlier. The earliness of the distribution was suggested to differ depending on the sport with which the individual had experience.

Abbreviations

ANOVA
analysis of variance
EMG
electromyography
EOG
electrooculography
LED
light-emitting diode
HSD
honestly significant difference
SD
standard deviation

Declarations

Ethics approval statement

In accordance with the Declaration of Helsinki, all subjects provided informed consent after receiving an explanation of the experimental protocol, which was approved by the ethics committee at Sapporo International University.

Competing interests

The authors declare no competing interests.

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Author Contribution

KK and KF presented all the idea of this study, planed the method, directed the experiments, interpreted the results, and were major contributors to the writing of the manuscript. CY and FS directed the

experiments, interpreted the data, and were contributors to the writing of the manuscript. The authors read and approved the final manuscript.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Table

Table 1 is available in the Supplementary Files section.

Figures

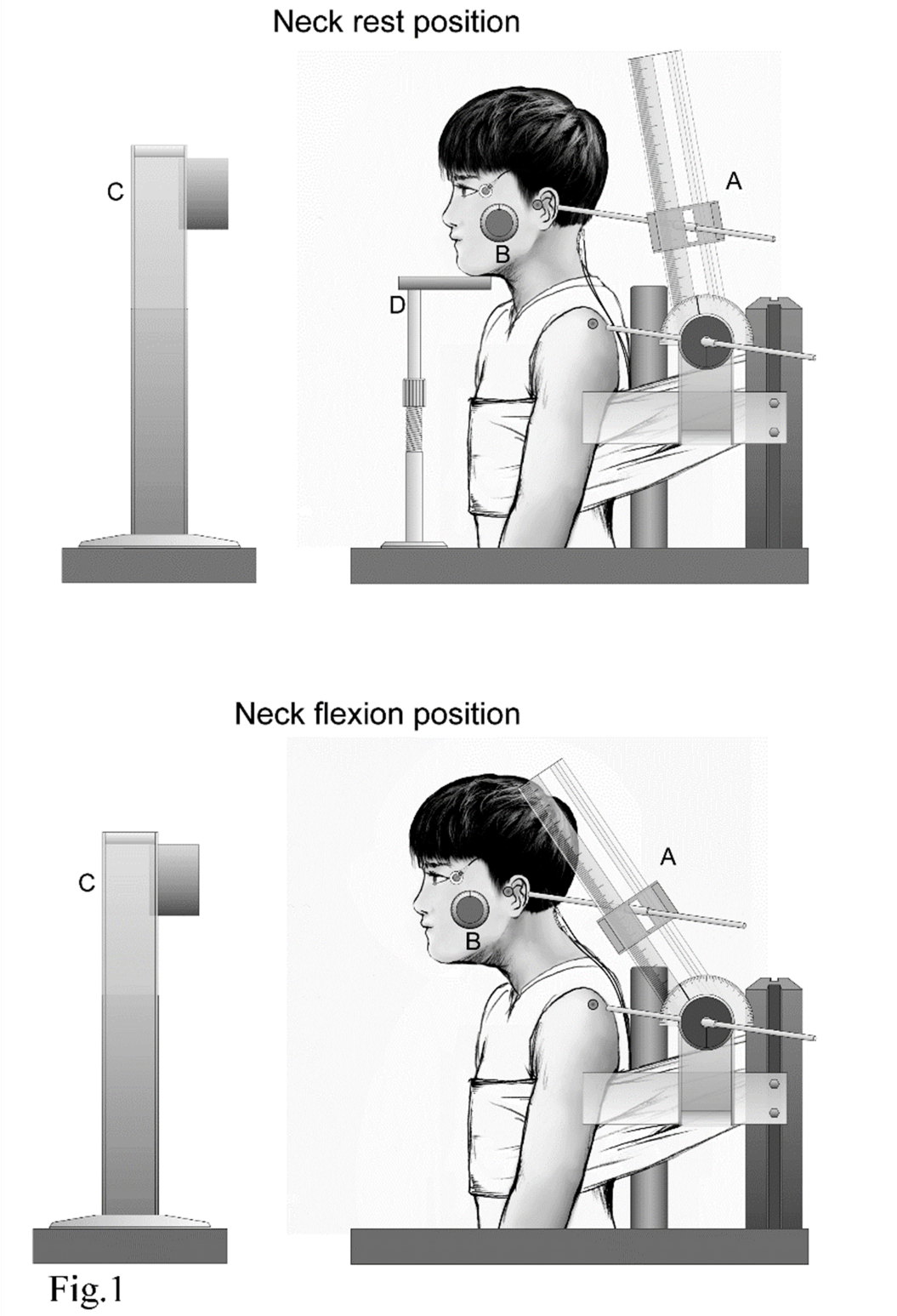


Figure 1

Experimental setup. A) Neck angle detector; B) angle detector using the pendulum principle; C) visual stimulator; D) chin stand.

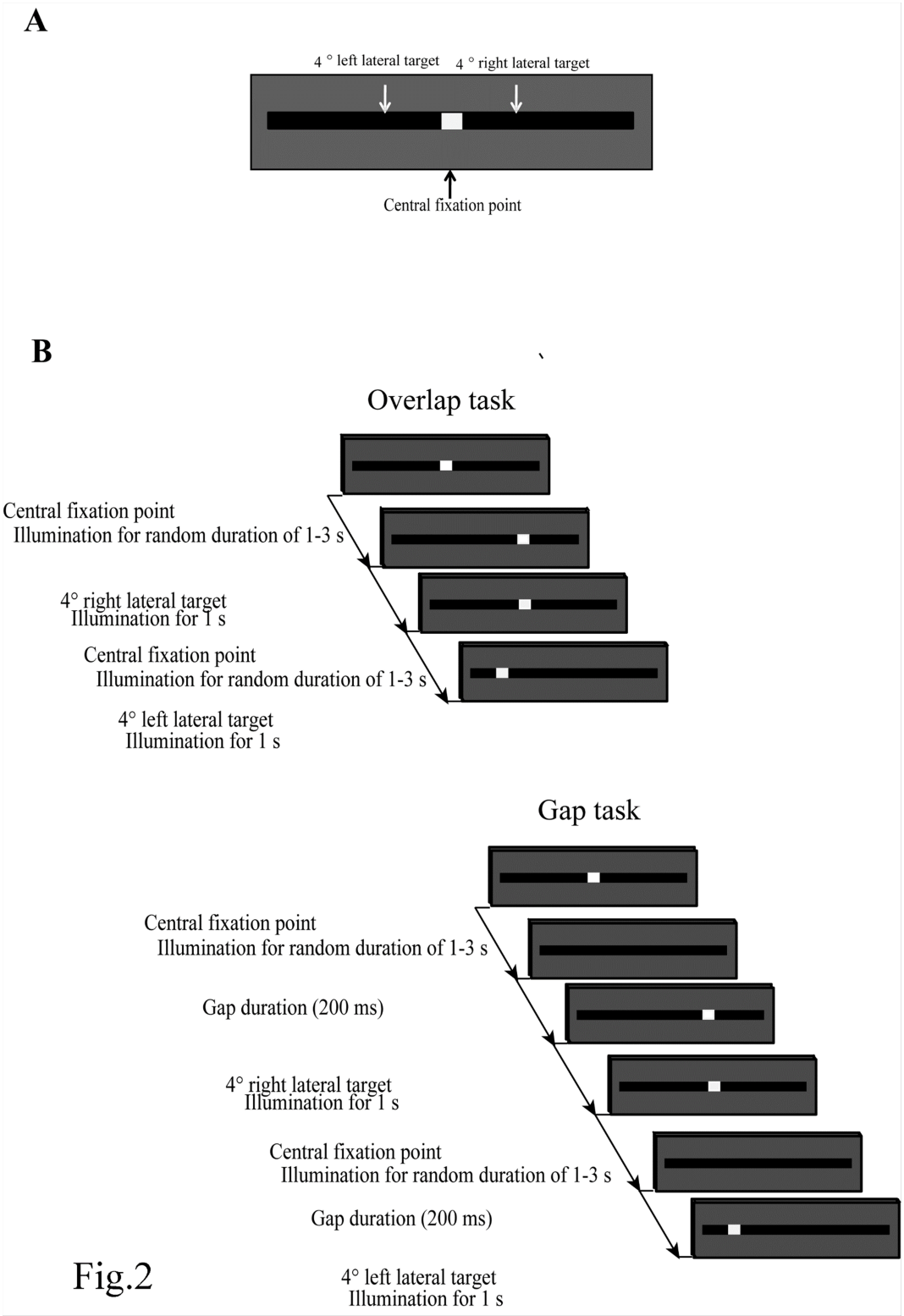


Figure 2

Pro-saccade reaction task

A) Two lateral targets located at 4° to the left and right of the central fixation point.

B) Presentation protocol in the pro-saccade task.

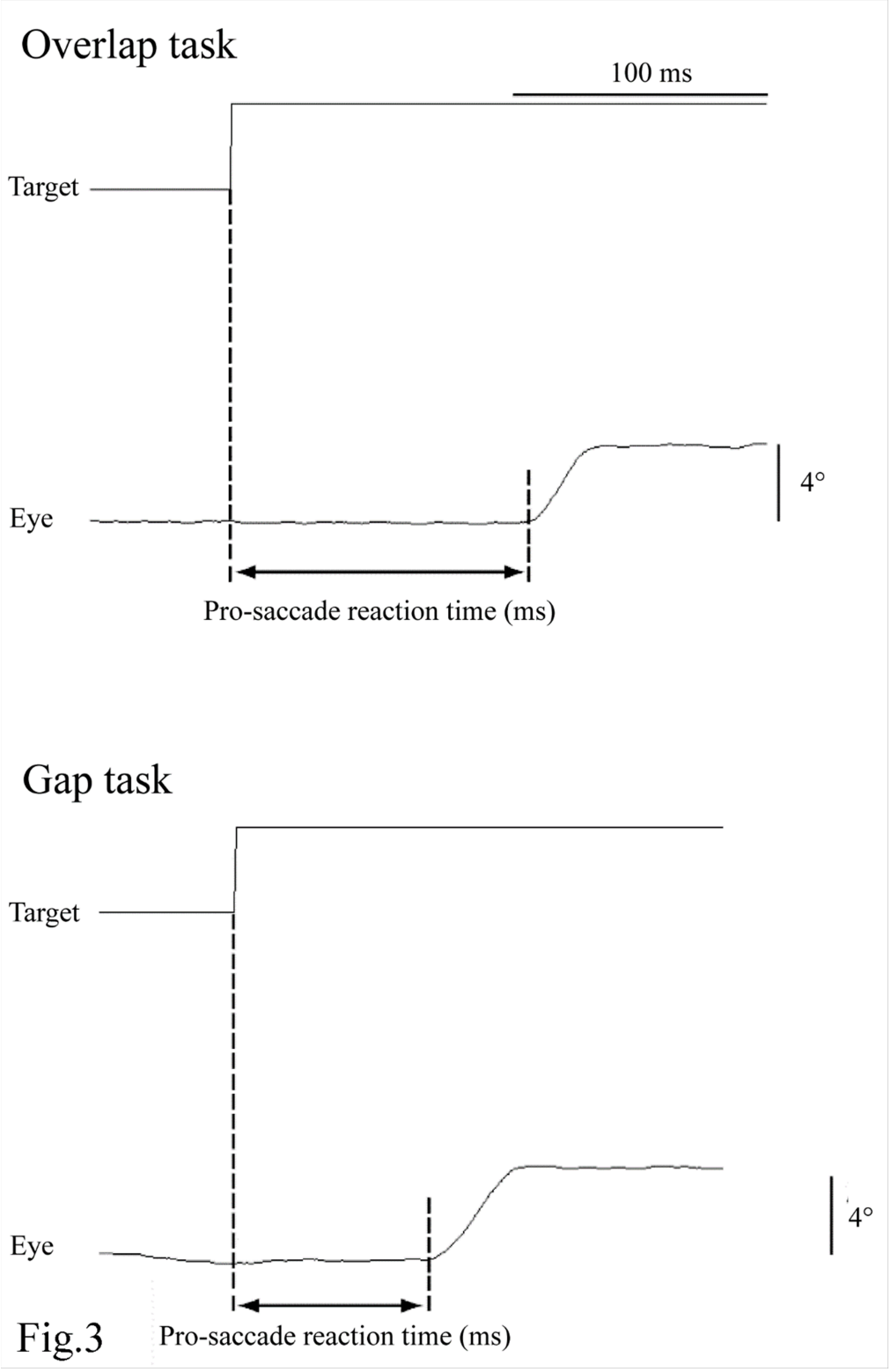


Figure 3

Analysis of pro-saccade reaction time.

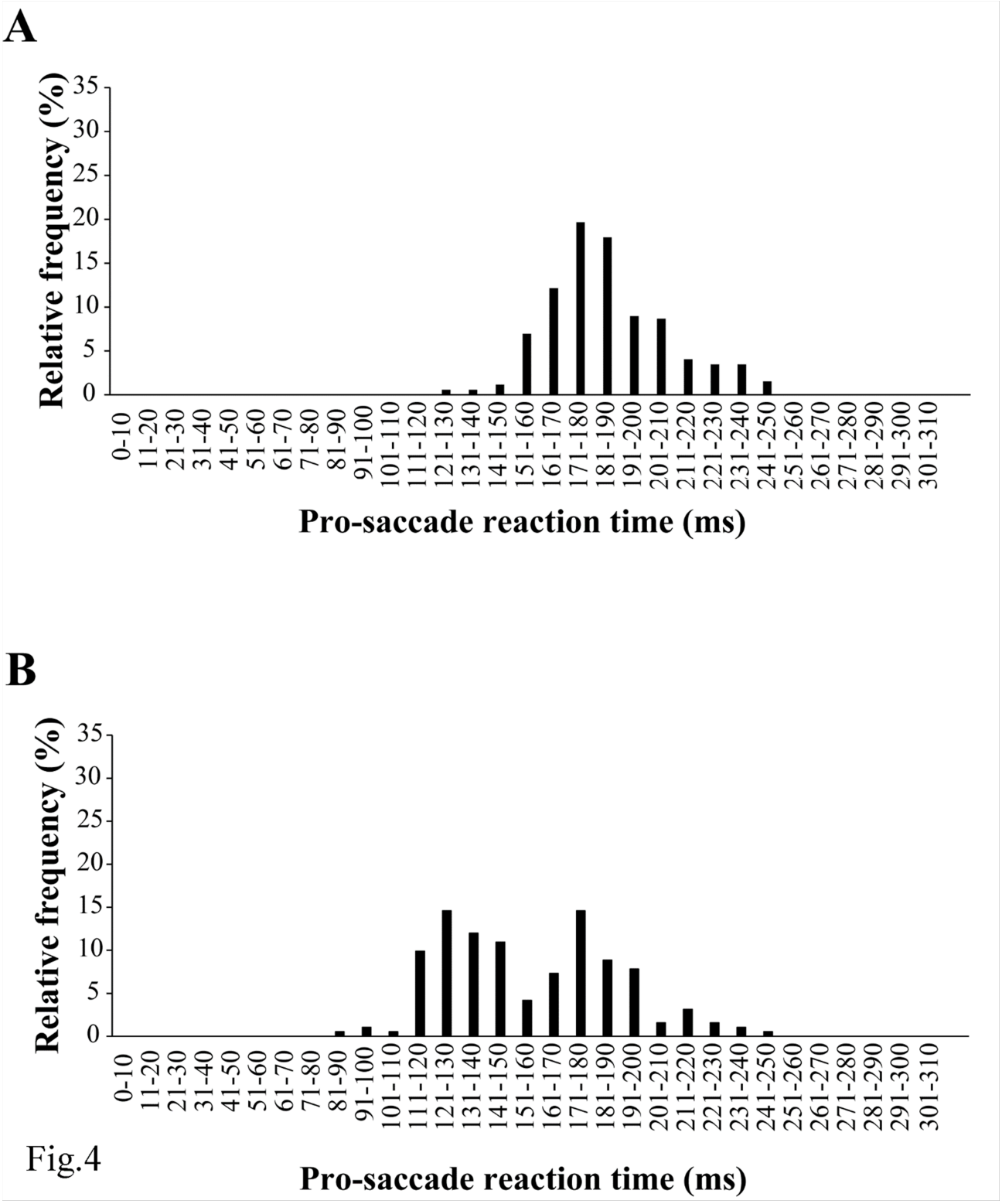


Figure 4

Representative histogram of relative frequencies for pro-saccade reaction time.

A) unimodal distribution. B) bimodal distribution.

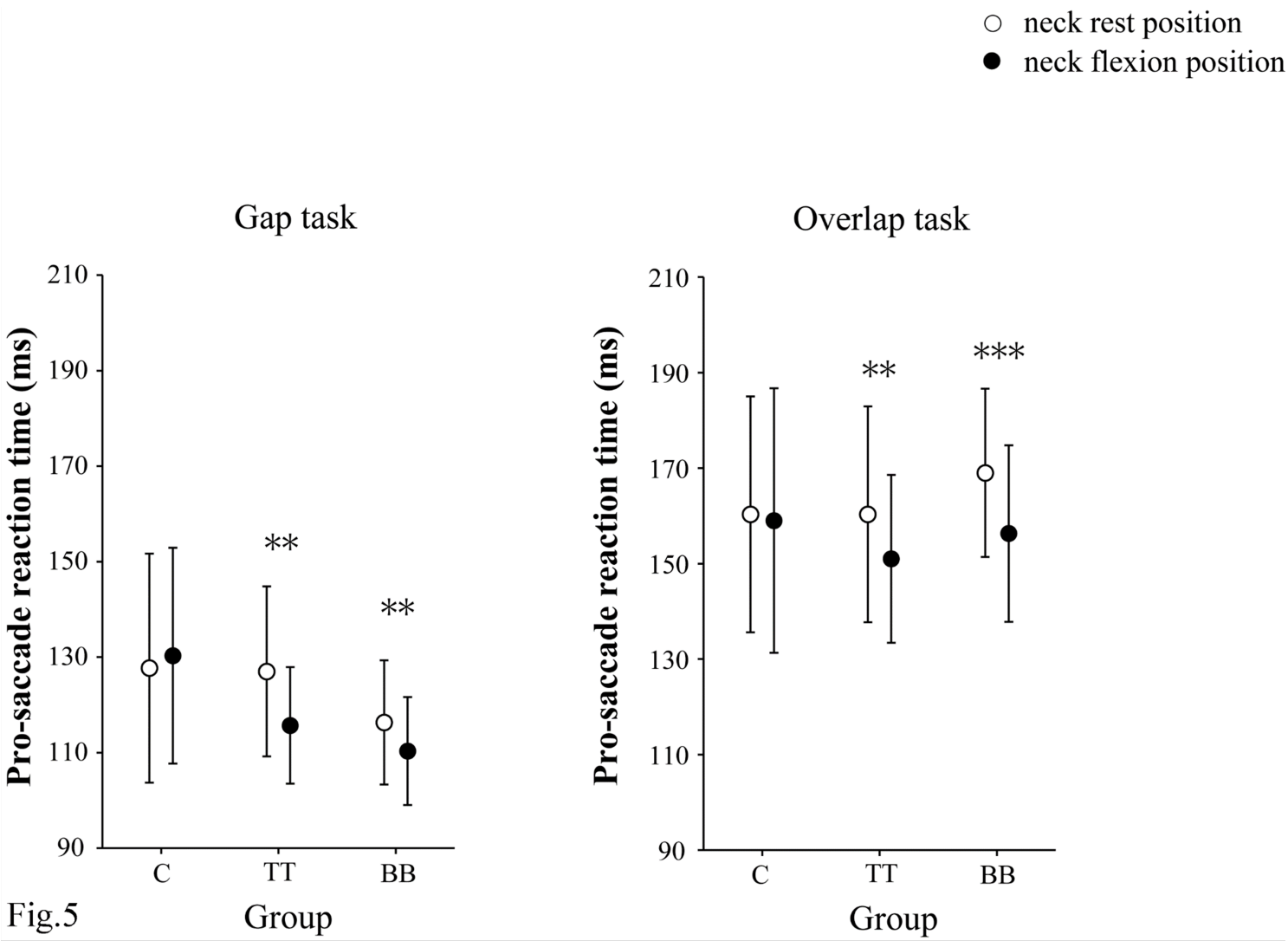


Figure 5

Mean and SD of median bandwidth observed for the earliest peak of relative frequenciesof pro-saccade reaction time. * Significant difference between postural conditions. **: $p < 0.01$; ***: $p < 0.001$.

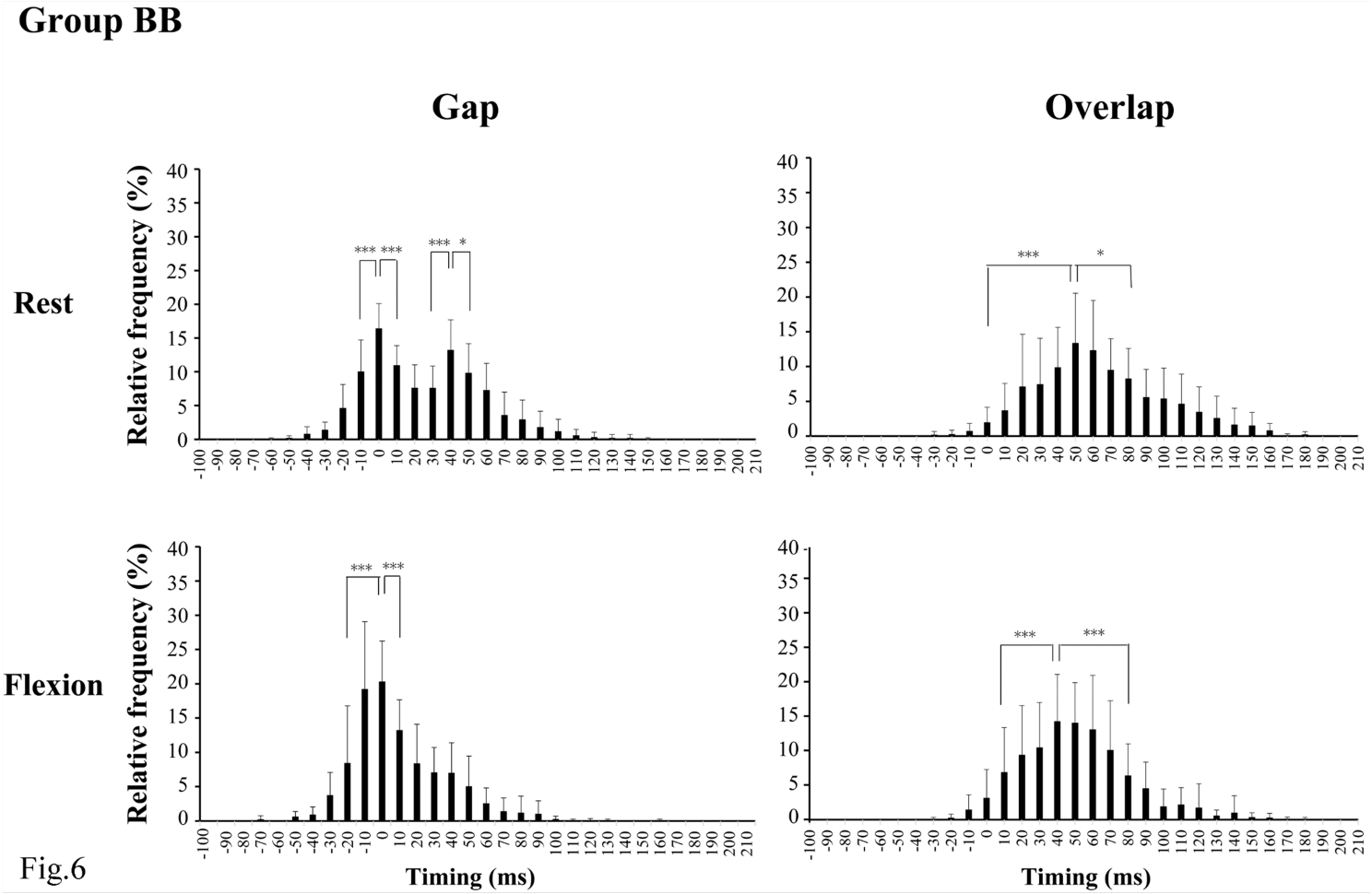


Fig.6

Figure 6

Mean and SD of relative frequencies for overlap and gap tasks in Group BB. * Nearest adjacent bandwidths showing significant reductions, compared to each peak bandwidth. *: $p < 0.05$; ***: $p < 0.001$.

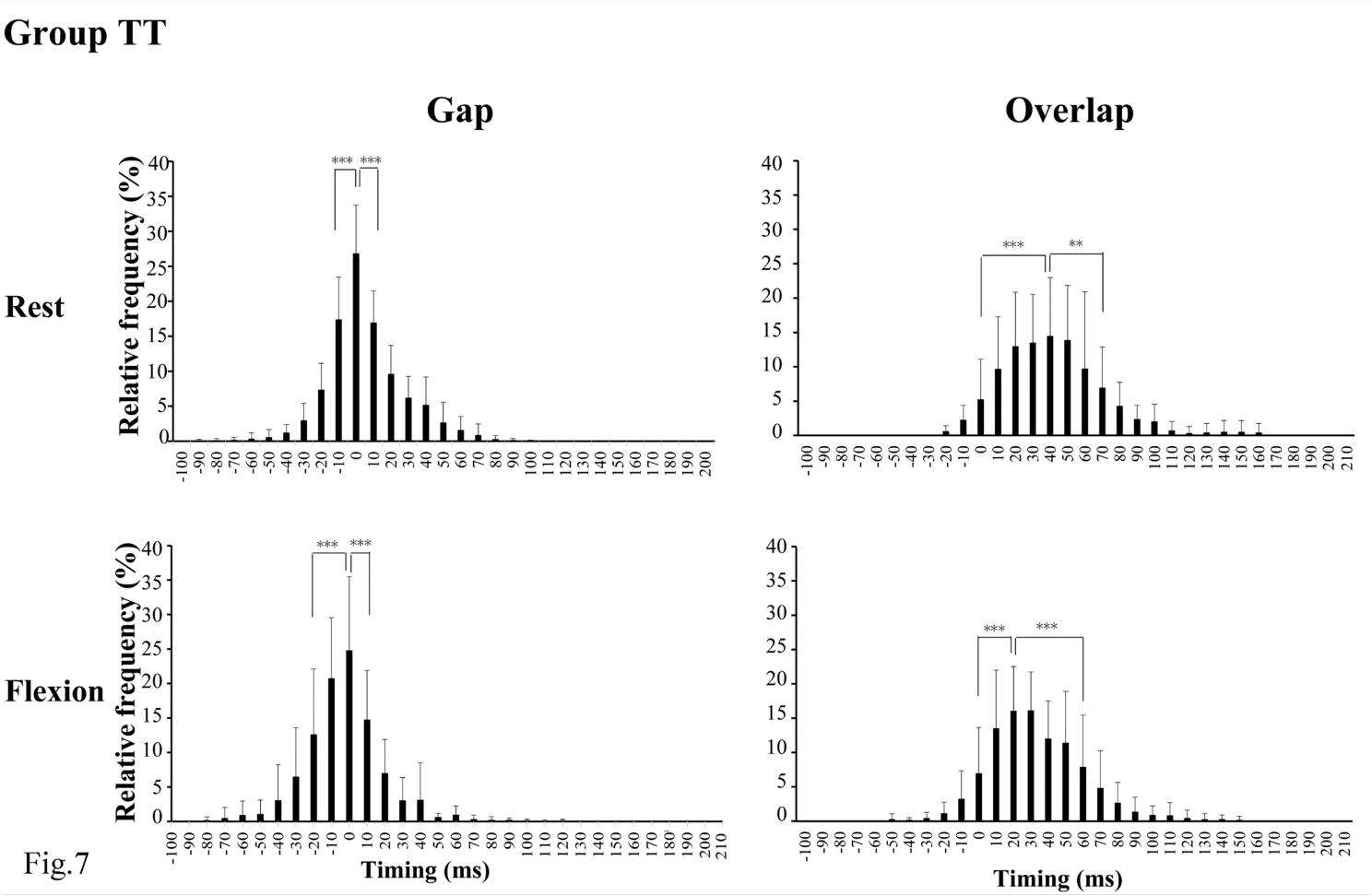


Fig.7

Figure 7

Mean and SD of relative frequencies for overlap and gap tasks in Group TT. * Nearest adjacent bandwidths showing significant reductions, compared to each peak bandwidth. **: $p < 0.01$; ***: $p < 0.001$.

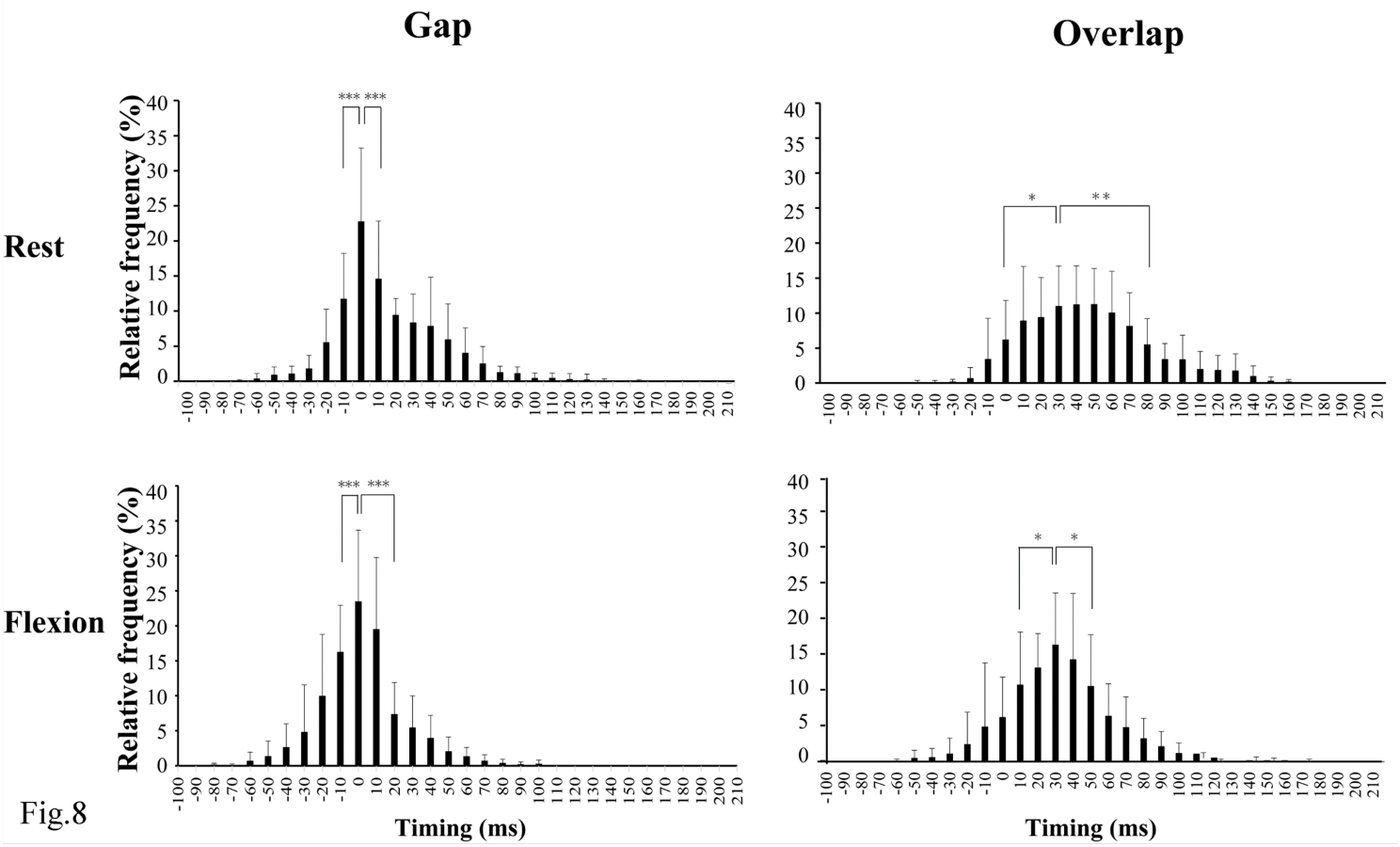


Fig.8

Figure 8

Mean and SD of relative frequencies for overlap and gap tasks in Group C. * Nearest adjacent bandwidths showing significant reductions, compared to each peak bandwidth. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

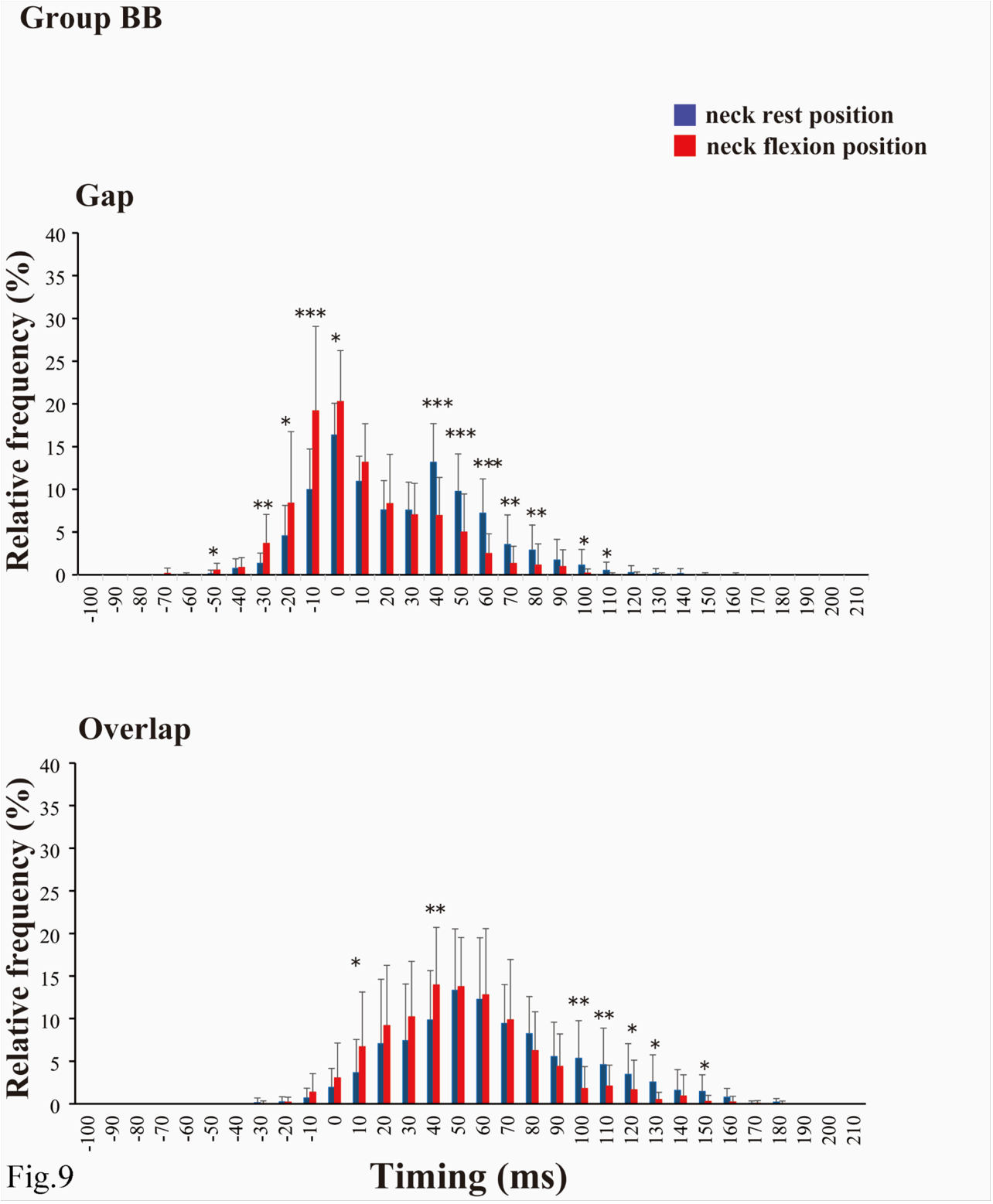


Figure 9

Comparison of mean value of relative frequencies between postural conditions in Group BB. * Significant difference between postural conditions. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

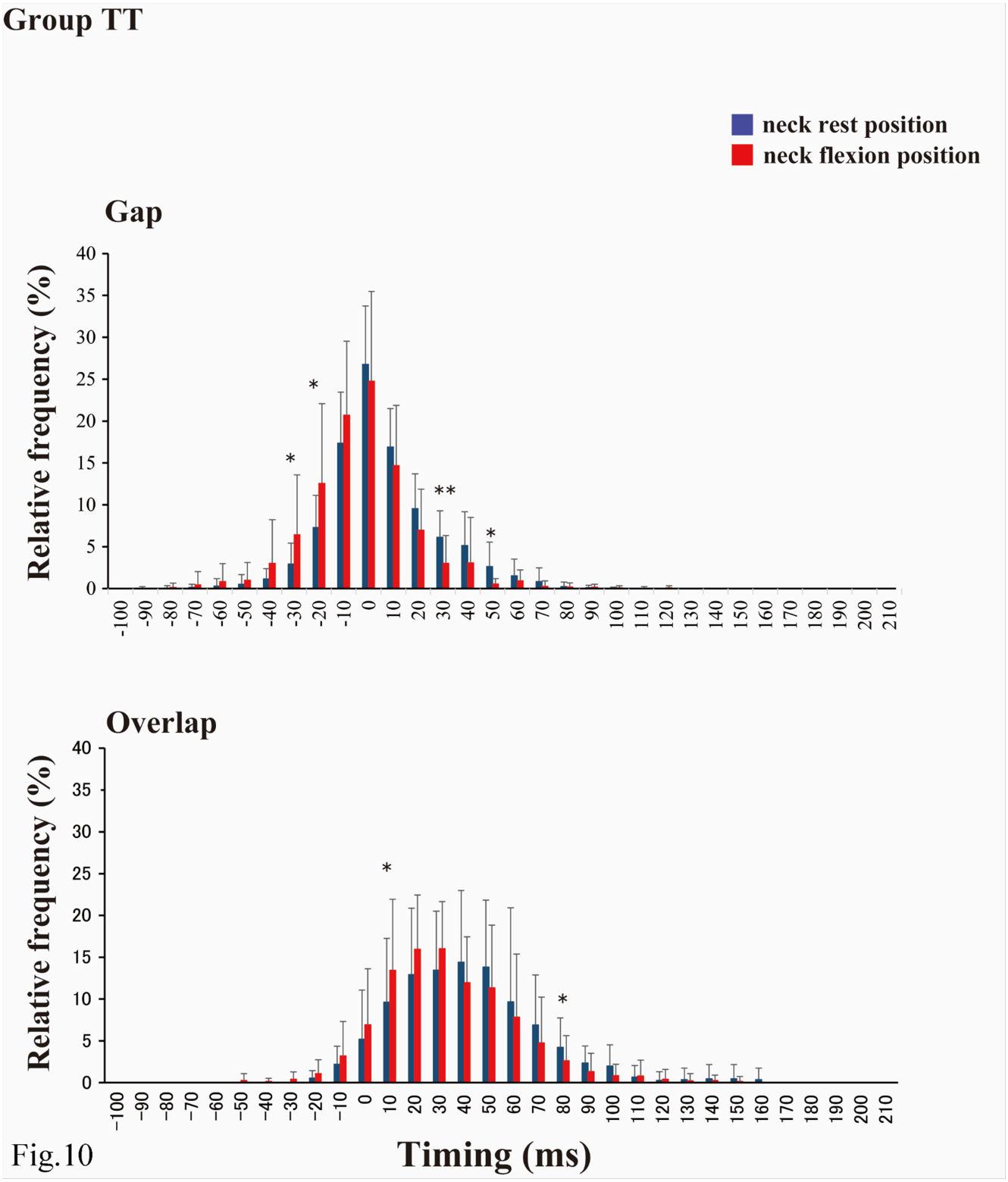


Figure 10

Comparison of mean values of relative frequencies between postural conditions in Group TT. * Significant difference between postural conditions. *: $p < 0.05$; **: $p < 0.01$.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.tif