

4.3.2 The influence of an occlusal alteration on jaw muscles

4.3.2.1 Laterotrusion with high closing force at slow speed

In summary, under the occlusal alteration at the high-closing-force laterotrusion in 14 subjects, the bilateral anterior temporalis and masseter muscles showed a lower activity, especially on the ipsilateral (working) side, while the EMG activity in the contralateral IHLP was higher, especially at the return phase. There was no significant effect on the bilateral posterior temporalis muscles in most subjects. Fig. 4.3-33 shows mid-incisor point (MIPT) movement and raw EMG data from one trial in one subject under the three conditions of control 1, with the occlusal alteration, and under the control 2 conditions at the high closing-force level. Table 4.3-4 summarizes the influence of an occlusal alteration on jaw muscle activity within individual subjects.

MIPT movement assessment

The mean onset and offset times of three-dimensional MIPT movements under each condition was calculated for each subject. A comparison between the three conditions when the data from all subjects were grouped showed no significant difference. The average onset of MIPT movement for all subjects (at ~2.9 s) or offset (at ~11.1 s) was slightly later than the instructed onset indicated by the LED target (at 2.6 s) or offset (at 10.8 s).

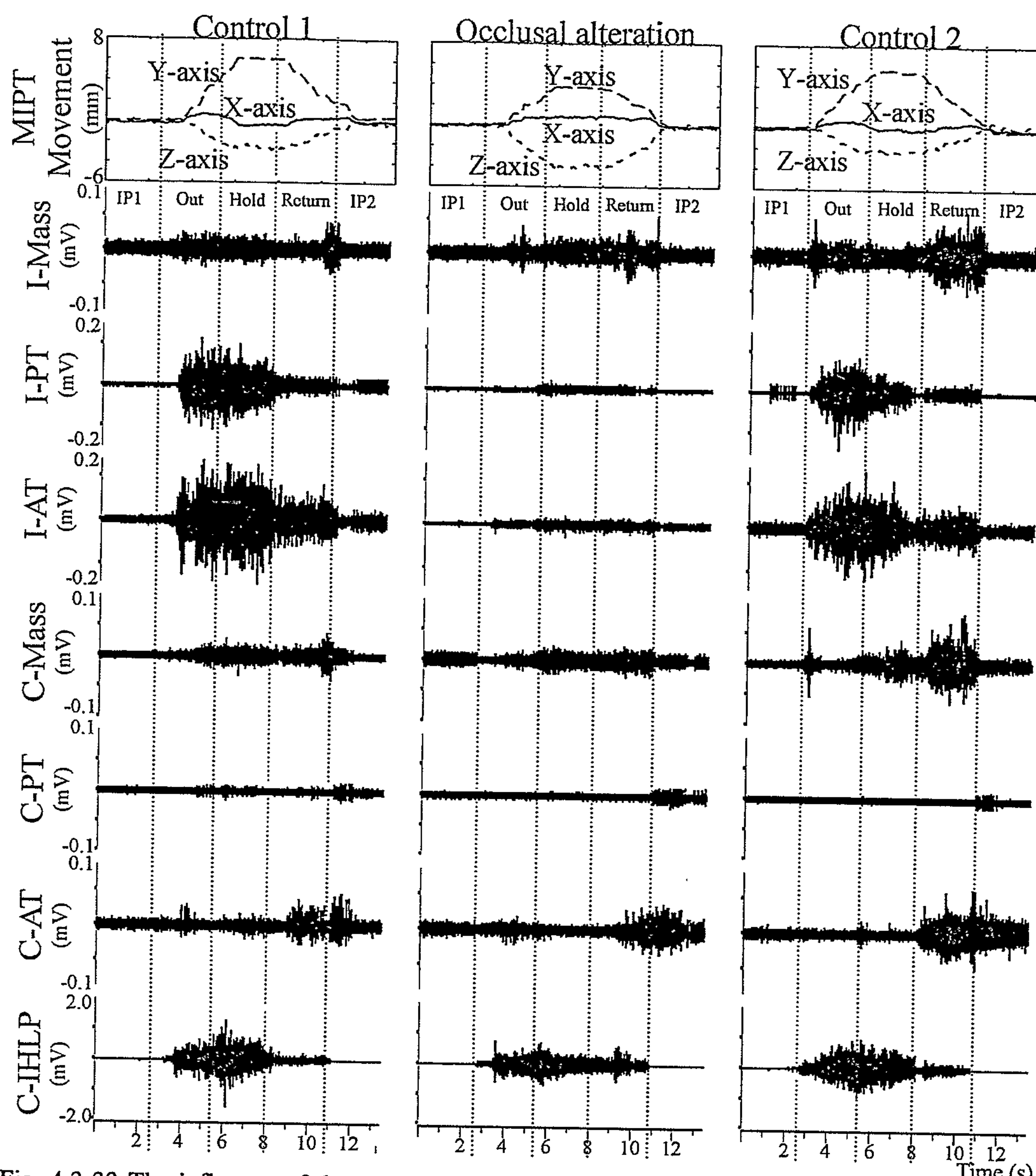


Fig. 4.3-33 The influence of the occlusal alteration on jaw muscles during laterotrusion at high closing force level. Examples of raw EMG activity under the control 1, occlusal alteration and control 2 conditions are displayed. Each vertical dotted line separates two phases. Each trace of muscle activity is displayed at the same amplitude under three conditions. C-: contralateral side to the occlusal alteration and the direction of laterotrusion; I-: ipsilateral side; IHLP: inferior head of lateral pterygoid; AT: anterior temporalis; PT: posterior temporalis; Mass: masseter; IP1: intercuspal position 1 phase; Out: outgoing phase; Hold: holding phase; IP2: intercuspal position 2 phase; MIPT: mid-incisor point; X-axis: antero-posterior axis; Y-axis: medio-lateral axis; Z-axis: supero-inferior axis.

Contralateral inferior head of the lateral pterygoid muscle

Overall quantitative comparison

For all subjects grouped together, the mean EMG activity of the contralateral IHLP at the outgoing phase under the occlusal alteration and control 2 conditions was significantly higher than that under the control 1 condition. The mean IHLP

activity under the occlusal alteration was higher than that under the control 2 condition but without statistical significance. There was no difference between the three conditions at the holding phase. At the return phase, the mean contralateral IHLP activity under the occlusal alteration was significantly higher than that under the control 1 and 2 conditions, and there was no significant difference between the control 1 and 2 conditions. Fig. 4.3-34 (A) displays the mean EMG activity of the contralateral IHLP from each subject under the three occlusal conditions at the outgoing, holding and return phases. The occlusal alteration caused an increase in contralateral IHLP activity principally at the return phase. At the outgoing phase, the EMG activity of five (of nine) subjects did not return toward the control 1 level under the control 2 condition.

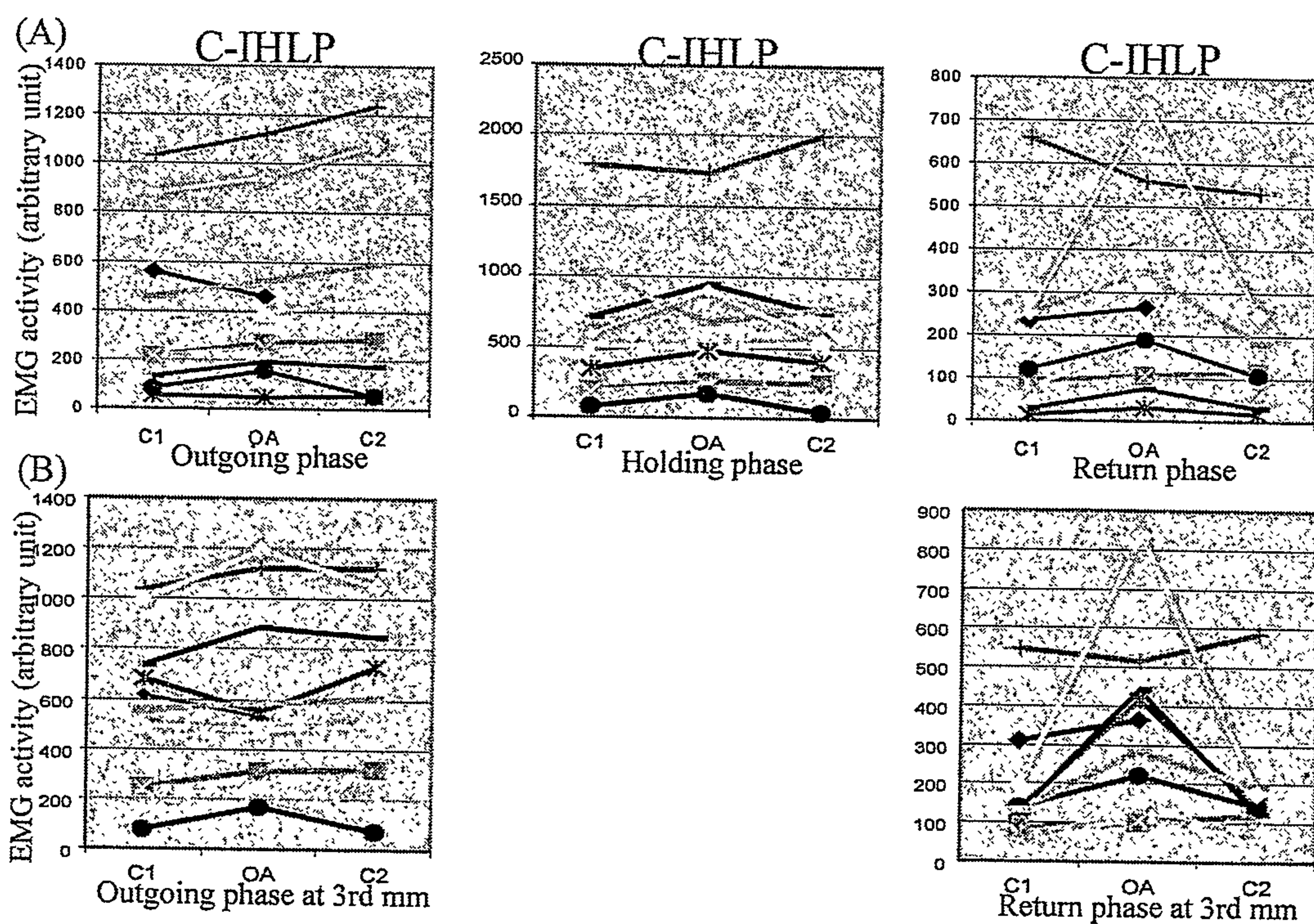


Fig. 4.3-34 The effect of the occlusal alteration on the mean EMG activity of the contralateral IHLP of each subject is displayed. (A) Mean EMG activity of each phase. (B) Mean EMG activity when MIPT was 3 mm away from intercuspal position. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

(A) Outgoing phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	5	4 (2)	1	4	5 (1)		3	6 (1)	
	entire	4	5 (2)	1	3	6 (1)		1	8 (1)	
C_AT			7 (2)	2		7 (1)	2		7 (1)	2
C_PT		1	5 (2)		1	5 (1)		1	5 (1)	
C_MASS		1	8 (2)	5	1	7 (1)	5	1	11 (1)	1
C_SubMand			3			3			3	
I_AT			5 (1)	9 (1)		5 (1)	8		7 (1)	6
I_PT		2	4 (1)	4	2	4 (1)	3	1	5 (1)	3
I_MASS			6 (1)	7 (1)		8 (1)	5		9 (1)	4
I_SubMand		1	4		1	4			5	

(B) Holding phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP										
	entire	4	5 (1)	1 (1)	4	4 (1)	1	3	6 (1)	
C_AT		1	5 (2)	3	1	6 (1)	2		8 (1)	1
C_PT		1	4 (2)	1	1	5 (1)		1	5 (1)	
C_MASS		1	9 (2)	4	1	8 (1)	4	1	10 (1)	2
C_SubMand			3			3			3	
I_AT			5 (1)	9 (1)		5 (1)	8	1	6 (1)	6
I_PT		1	6 (1)	3	1	5 (1)	3	1	6 (1)	2
I_MASS			7 (1)	6 (1)		8 (1)	5		10 (1)	3
I_SubMand		1	4		1	4		1	4	

(C) Return phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	7	3 (2)		7	2 (1)		6	3 (1)	
	entire	7	3 (2)		7	2 (1)		7	2 (1)	
C_AT		1	6 (2)	2		7 (1)	2		8 (1)	1
C_PT		1	4 (2)	1	1	4 (1)	1		6 (1)	
C_MASS			11 (2)	3		11 (1)	2		11 (1)	2
C_SubMand		1	2			3			3	
I_AT			9 (1)	5 (1)		9 (1)	4		11 (1)	2
I_PT		1	5 (1)	4		7 (1)	2		7 (1)	2
I_MASS		(1)	9	4 (1)	(1)	11	2		11 (1)	2
I_SubMand		1	4		1	4		1	4	

Table 4.3-4 A summary of the influence of the occlusal alteration on jaw-muscle EMG activity at the (A) outgoing, (B) holding and (C) return phases within each subject during laterotrusion at high closing force. The numbers indicate the number of subjects who showed a statistically significantly higher (S/S higher) activity, no significant influence (no S/S), or significantly lower (S/S lower) activity under the occlusal alteration. The number in brackets is the results of the two sham overlay subjects. The first row of C_IHLP in (A) and (C) shows the comparison between EMG activity at 3 mm away from intercusp position at the outgoing and return phases (with normalizing method one), respectively, and the second row shows the comparison between the EMG of the entire phase. Criterion 1, 2 and 3 refer to analyzes performed under progressively more stringent criteria (see Methods). In one occlusal-alteration subject and one sham-overlay subject, the EMG activity under the control 2 condition was not recorded, therefore, their data was not included in Criterion 2 and 3. C_: contralateral; I_: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter; SubMand: submandibular muscles.

A comparison of the mean EMG activity when the MIPT was 3 mm (three-dimensionally) away from intercuspal position, showed that there was no significant difference between the three conditions at the outgoing phase. At the return phase, the IHLP activity under the occlusal alteration condition was significantly higher than that under the control 1 and 2 conditions, and the IHLP activity under the control 2 condition was significantly higher than that under the control 1 condition. Fig. 4.3-34 (B) shows the mean EMG activity of the contralateral IHLP from each subject under the three occlusal conditions at 3 mm away from the intercuspal position for the outgoing and return phases. The occlusal alteration caused a significant increase in the contralateral IHLP activity principally at the return phase.

Comparison within individual subjects

A comparison between the three conditions within individual subjects (Table 4.3-4) showed that the occlusal alteration was mainly associated with a higher activity (especially at the return phase; Table 4.3-4 (C)) or no influence in contralateral IHLP activity whether Criterion 1, 2 or 3 were used. The other jaw muscles however showed a lower or no influence on IHLP activity due to the occlusal alteration, and these muscles will be described in detail below. The two subjects with the sham overlays showed that the contralateral IHLP activity was not changed due to the attachment of the sham overlay (Table 4.3-4) except in one subject at the holding phase where a significant decrease was observed. However, because the control 2 recordings were not available in this subject, it is not possible to rule out fatigue that might have occurred in this subject.

Onset and offset time difference between MIPT movement and EMG activity

Subjects	Onset			Offset		
	Control 1	Occlusal alteration	Control 2	Control 1	Occlusal alteration	Control 2
1	0.91	-0.09		0.11	1.05	
2	0.61	0.47	0.55	0.07	-0.13	-0.18
3	0.5	0.52	0.97	0.96	0.22	1.29
4	0.69	0.54	0.28	-0.15	0.01	0.28
5	0.02	0.02	0.06	3.52	0.73	3.47
6	-0.18	-0.62	-1.14	-0.1	0.35	2.08
7	0.53	0.84	0.76	0.11	0.11	0.32
8	0.37	0.12	0.13	2.66	0.65	2.43
9	0.23	0.81	0.65	0.24	-0.27	0.49
10	0.63	0.57	0.36	-0.01	-0.91	-0.11
Mean $\pm$ SD	0.43 $\pm$ 0.33	0.32 $\pm$ 0.46	0.29 $\pm$ 0.61	0.74 $\pm$ 1.29	0.18 $\pm$ 0.56	1.12 $\pm$ 1.28

Table 4.3-5 The mean onset and offset time difference between the MIPT movement and contralateral IHLP activity from each subject under the three occlusal conditions during laterotrusion at high closing force level. Positive values indicate that, in this subject, the IHLP activity started (or stopped) earlier than the MIPT displacement.

The occlusal alteration did not change the onset time difference between IHLP and MIPT movement (Table 4.3-5). The difference between the offset times of IHLP and MIPT movement was smaller under the occlusal alteration than that under the control 1 and control 2 conditions (Table 4.3-5) but without statistical significance ($p=0.073$ and 0.090 , respectively).

Difference in results between three normalizing methods

The results of two methods of normalizing EMG activity at the 3rd mm of MIPT movement were similar to each other at the high closing force as well as at the low closing force at two speeds and during protrusion. There was a slight variation between the results of the comparison of EMG activity of the entire phases and the results of the comparison of EMG activity at 3 mm away from intercuspal position at the outgoing and return phases. For example, some subjects showed a significant difference at the 3rd mm of the MIPT displacement

at the outgoing phase due to the occlusal alteration, but no significant difference at the entire outgoing phase (e.g. Table 4.3-4 A). Further, although the overall comparison in the mean EMG activity in all subjects showed that there was a significantly higher activity in the entire-phase EMG comparison at the outgoing phase, there was no significant difference in the 3rd-mm EMG comparison.

Influence of occlusal alteration on IHLP activity associated with the electrode recording sites

Position	Subject	Outgoing	Holding	Return
Supero-medial	01	X	X	↑
	02	X	X	↑
	03	↑	↑	↑
	04	X	↓	↑
	05	↓	X	X
Infero-medial	06	X (↑)	↑	↑
	07	X (↑)	↑	X
	08	X	X	X

Table 4.3-6 The influence of the occlusal alteration on the contralateral IHLP activity associated with the electrode recording site in eight subjects where electrode position was verified by CT scan data. Position column indicates that, in these subjects, the recording sites were located in the supero- (or infero-) medial quarter of the IHLP. In the right three columns, the influence of the occlusal alteration on the IHLP during each entire phase is shown (based on Criterion 2, except Subject 05, in which the Criterion 1 result is shown due to the lack of the control 2 recordings). The symbols in brackets indicate the results at the 3-mm MIPT displacement, if differing to the results of the entire phase. Subjects in each quarter are listed in an arbitrary order. ↑: significantly higher due to the occlusal alteration; X: no significant changes; ↓: significantly lower.

The electrode positions, verified by CT images, were distributed along the medial half of the IHLP. In the return phase, the IHLP activity recorded from the supero-medial quarter showed a significantly higher activity under the influence of the occlusal alteration in all subjects except one, whereas that recorded from the infero-medial quarter showed a significantly higher activity only in one (of three) subjects (Table 4.3-6). More data are needed before any comments can be made about location and function on the return phase and on the outgoing and holding phases.

Qualitative comparison

A qualitative assessment, including the MIPT movement and raw EMG comparison (e.g. Fig. 4.3-33) and the superimposed averaged EMG plots (data not shown), showed that the occlusal alteration did not change the overall pattern of the contralateral IHLP activity described in Section 4.3.1.2. That is, under all three conditions, an increase occurred at the outgoing phase, a peak at the early holding phase, and then a return to the intercuspal position level of activity (e.g. Fig. 4.3-33). In addition, a comparison between the EMG activity at each mm of MIPT displacement showed that any effect of the occlusal alteration did not increase or decrease progressively as the MIPT moved progressively further away from the intercuspal position. In contrast, the most predominant change occurred when the MIPT was about 2 – 4 mm away from the intercuspal position in most of the subjects who showed a significant change due to the occlusal alteration, especially at the return phase (e.g. Fig. 4.3-35).

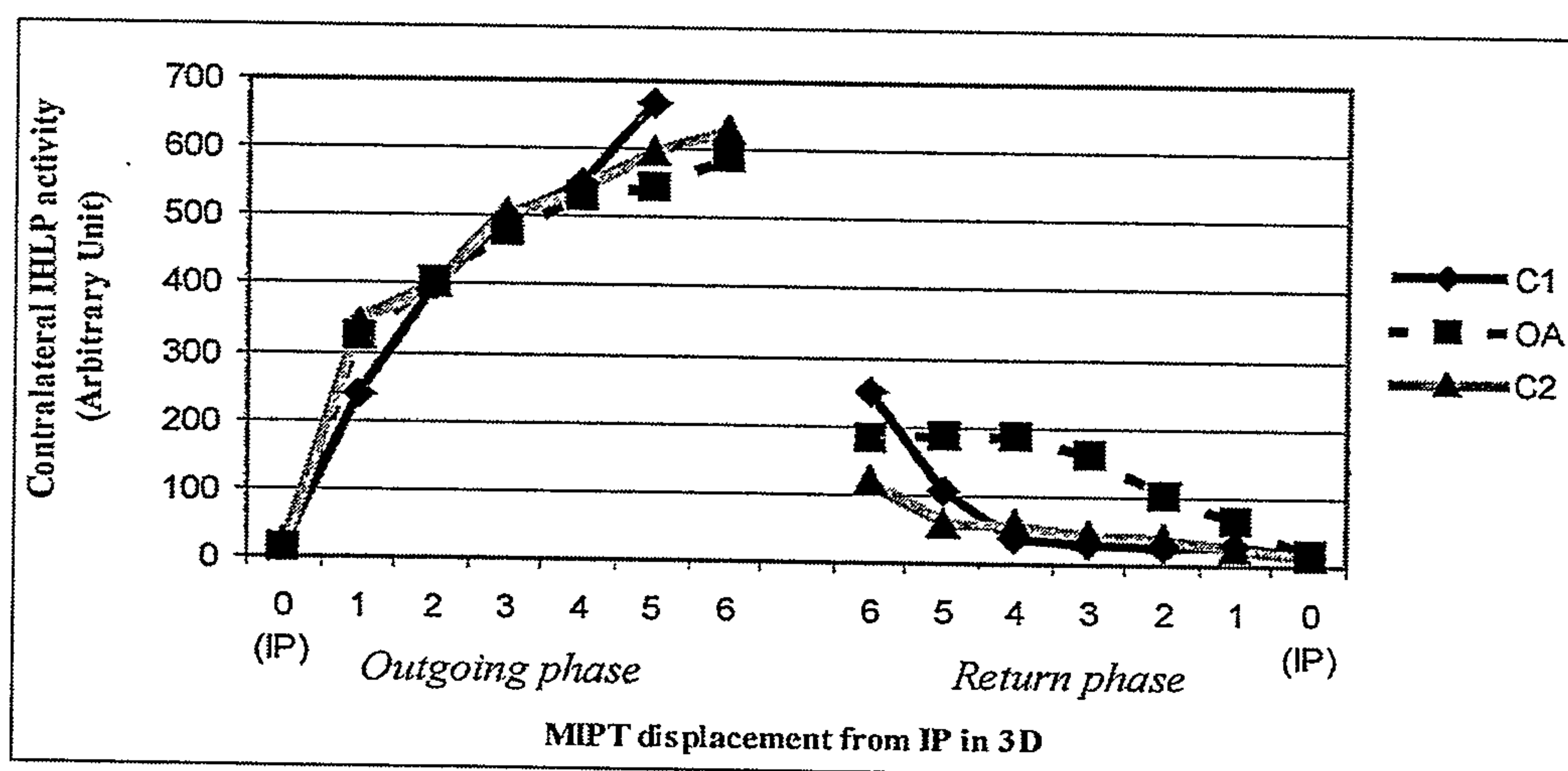


Fig. 4.3-35 The influence of the occlusal alteration on the contralateral IHLP activity at each mm of MIPT movement (with normalizing method one) during laterotrusion at high closing force in one subject. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

Contralateral anterior temporalis

For all subjects grouped together, a comparison of the mean EMG activity of the contralateral anterior temporalis between the three conditions showed a lower activity due to the occlusal alteration with a significant difference at the holding phase only. There was no significant difference between the control 1 and 2 conditions in the outgoing, holding and return phases. In Fig. 4.3-36, the occlusal alteration caused a decrease in contralateral anterior temporalis activity in most subjects.

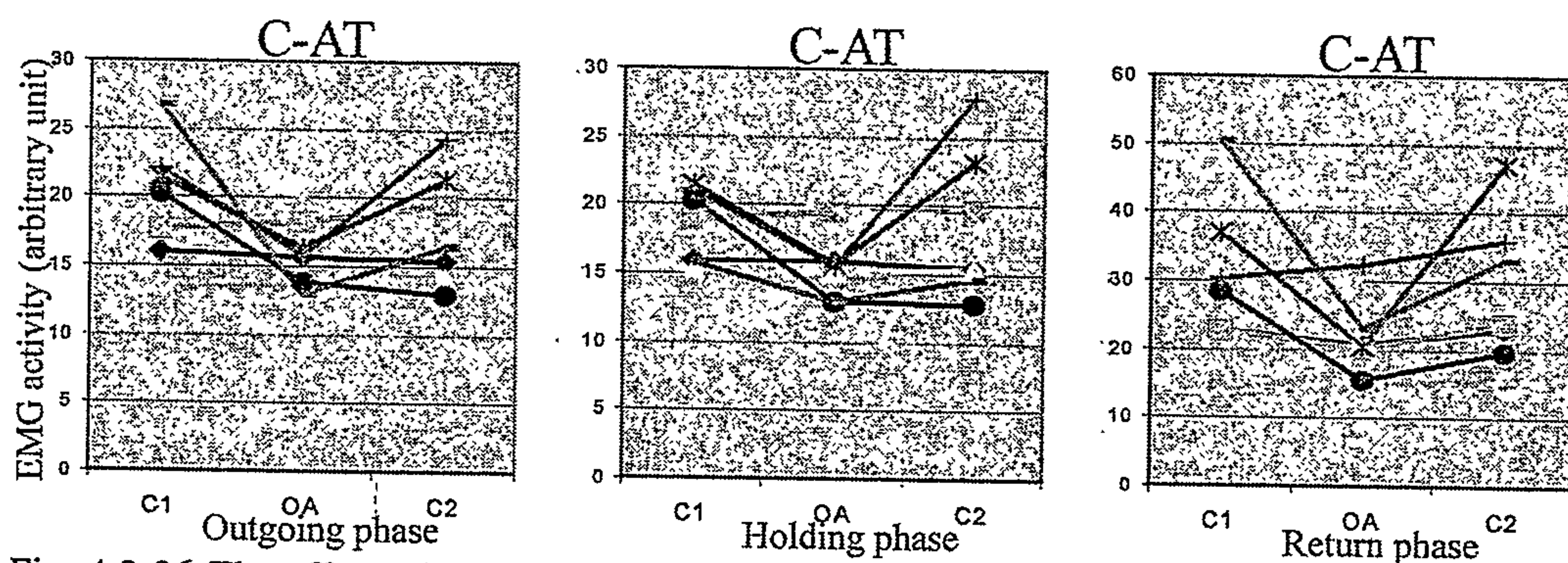


Fig. 4.3-36 The effect of the occlusal alteration on the mean EMG activity of the contralateral anterior temporalis of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

A comparison between the three conditions within individual subjects (Table 4.3-4) showed that the occlusal alteration did not change the contralateral anterior temporalis activity in most of the subjects or it caused a lower activity in some subjects. The sham overlay did not cause any change in the outgoing, holding and return phases. The qualitative assessment showed that the occlusal alteration did not change the overall pattern of the contralateral anterior temporalis activity (e.g. Fig. 4.3-33).

Contralateral posterior temporalis

There was no statistically significant difference between the mean EMG activity of the contralateral posterior temporalis under the three occlusal conditions in the outgoing, holding and return phases. In Fig. 4.3-37, the effect of the occlusal alteration was quite variable.

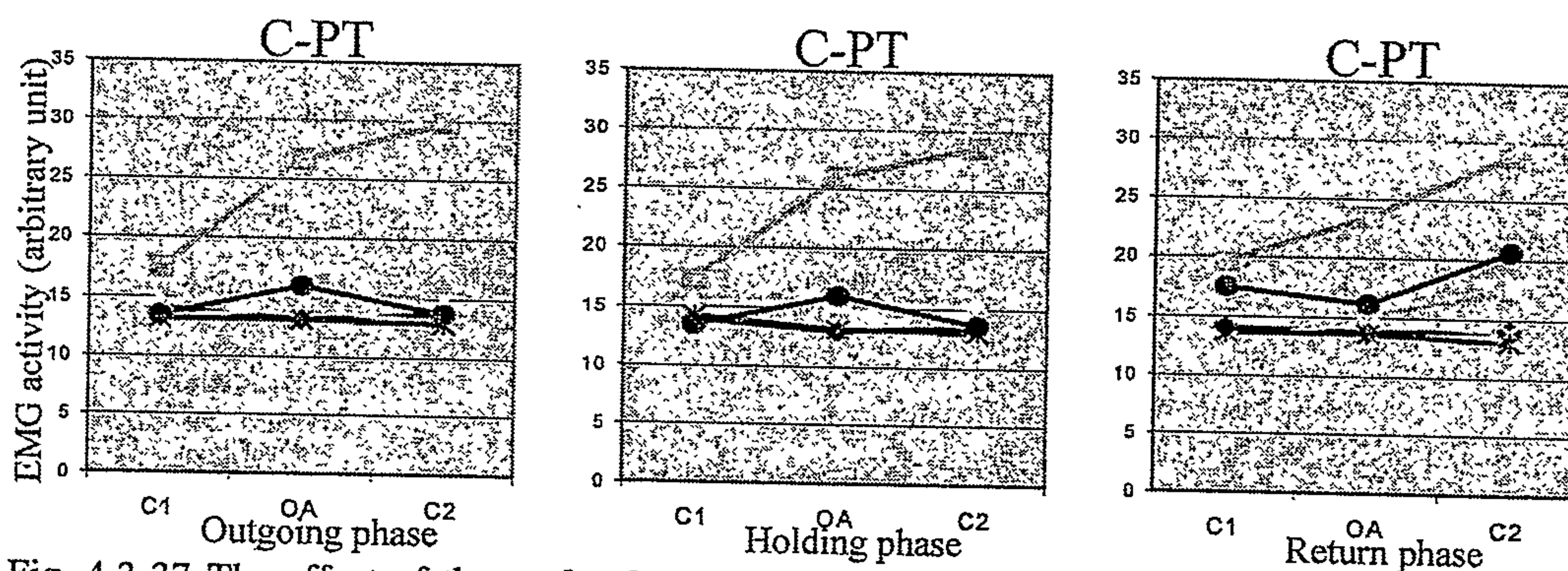


Fig. 4.3-37 The effect of the occlusal alteration on the mean EMG activity of the contralateral posterior temporalis of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

A comparison between the three conditions within individual subjects (Table 4.3-4) showed that the occlusal alteration usually did not change the contralateral posterior temporalis activity in most of the subjects. The sham overlay did not cause any change in the outgoing, holding and return phases. The qualitative assessment showed that the occlusal alteration did not change the overall pattern of the contralateral posterior temporalis activity (e.g. Fig. 4.3-33).

Contralateral masseter

A comparison in all subjects of the mean EMG activity of the contralateral masseter between the three conditions showed a lower activity due to the occlusal alteration with a significant difference between the control 1 and occlusal alteration conditions at the outgoing and holding phases. There was no

significant difference on the return phase for a comparison between control 1 and occlusal alteration. There was no statistically significant difference between the control 1 and 2 conditions and between the control 2 and occlusal alteration conditions in all three phases. The data for all subjects is shown in Fig. 4.3-38.

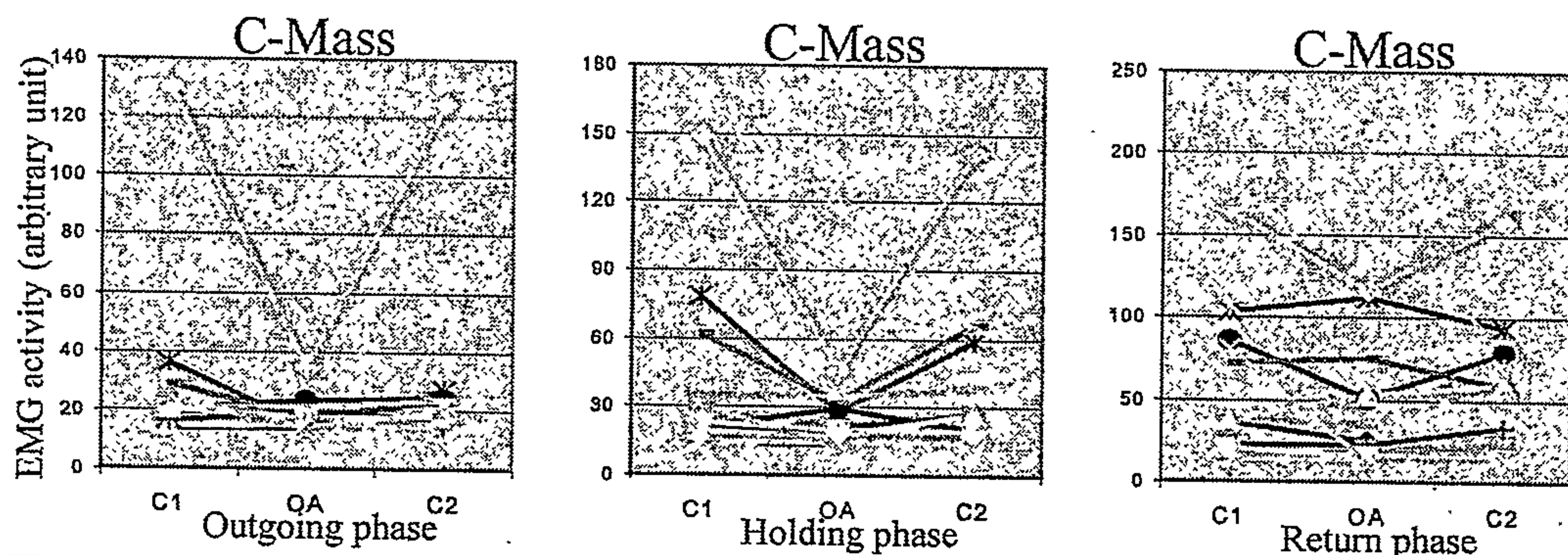


Fig. 4.3-38 The effect of the occlusal alteration on the mean EMG activity of the contralateral masseter of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

The comparison between the three conditions within individual subjects (Table 4.3-4) showed that the occlusal alteration did not change the contralateral masseter activity in most of the subjects and it caused a lower activity in some subjects (especially at the outgoing and holding phases). The sham overlay did not cause any change in the outgoing, holding and return phases. The qualitative assessment (e.g. Fig. 4.3-33) showed that the occlusal alteration did not change the overall pattern of the contralateral masseter activity.

Contralateral submandibular muscles

There was no significant difference between the mean EMG activity of the contralateral submandibular muscles under the three occlusal conditions in the outgoing, holding and return phases (see Fig. 4.3-39).

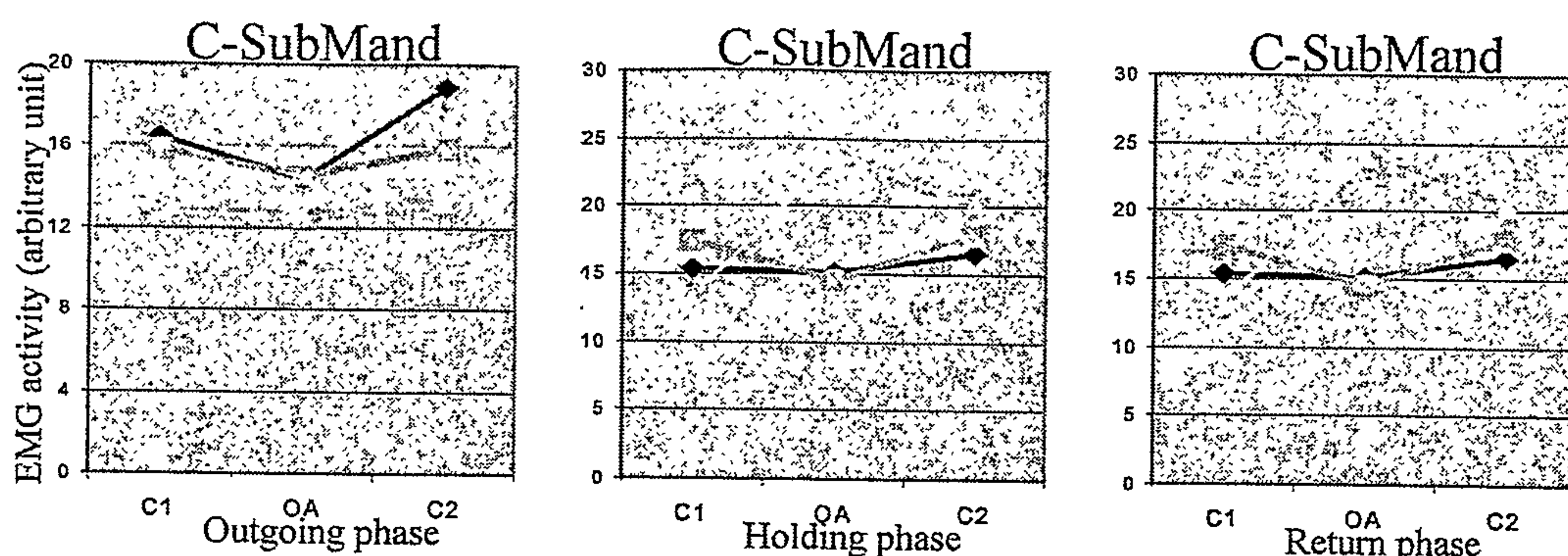


Fig. 4.3-39 The effect of the occlusal alteration on the mean EMG activity of the contralateral submandibular muscles of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

Table 4.3-4 shows that the occlusal alteration did not change the contralateral submandibular muscle activity within all subjects when the EMG activity at the control 2 condition was taken into consideration (Criteria 2 and 3 in Table 4.3-4). The qualitative assessment also showed that the occlusal alteration did not change the overall pattern of the contralateral submandibular muscle activity.

Ipsilateral anterior temporalis

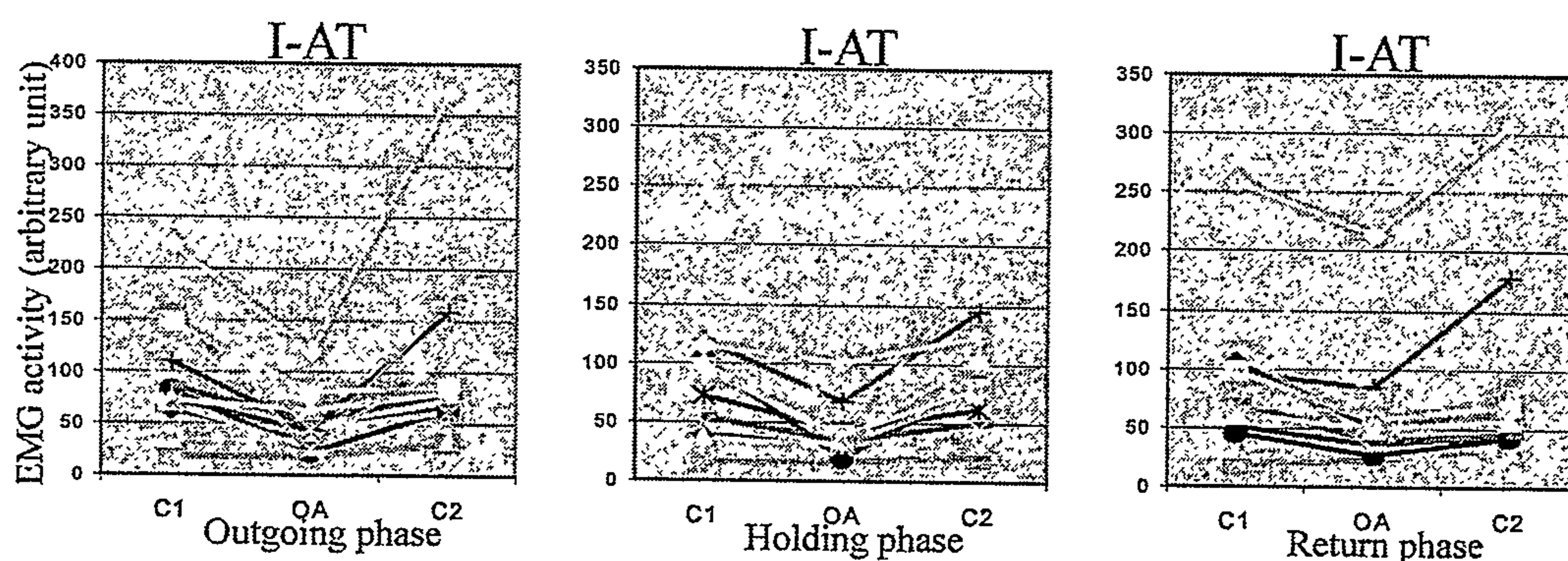


Fig. 4.3-40 The effect of the occlusal alteration on the mean EMG activity of the ipsilateral anterior temporalis of each subject under three occlusal conditions is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

A comparison of the mean EMG activity of the ipsilateral anterior temporalis showed a significantly lower activity with the occlusal alteration than that under the control 1 and 2 conditions in all three phases. There was no significant difference between the control 1 and 2 conditions, which indicated a full return

of EMG activity after the occlusal alteration had been removed. In Fig. 4.3-40, data from all subjects shows that the EMG activity under the occlusal alteration was lower than that under the control 1 and 2 conditions.

The comparison within individual subjects (Table 4.3-4) showed that most of the subjects showed a significantly lower activity due to the occlusal alteration especially at the outgoing and holding phases. In the two sham-overlay subjects, the occlusal alteration caused a lower activity in one subject and no influence in the other. Unfortunately, the control 2 EMG activity was not recorded in the sham-overlay subject who showed a lower activity under the occlusal alteration condition. Therefore, whether this change in activity was due to the sham overlay could not be assessed. The qualitative assessment (e.g. Fig. 4.3-33) showed that the occlusal alteration did not change the overall pattern of the ipsilateral anterior temporalis activity.

Ipsilateral posterior temporalis

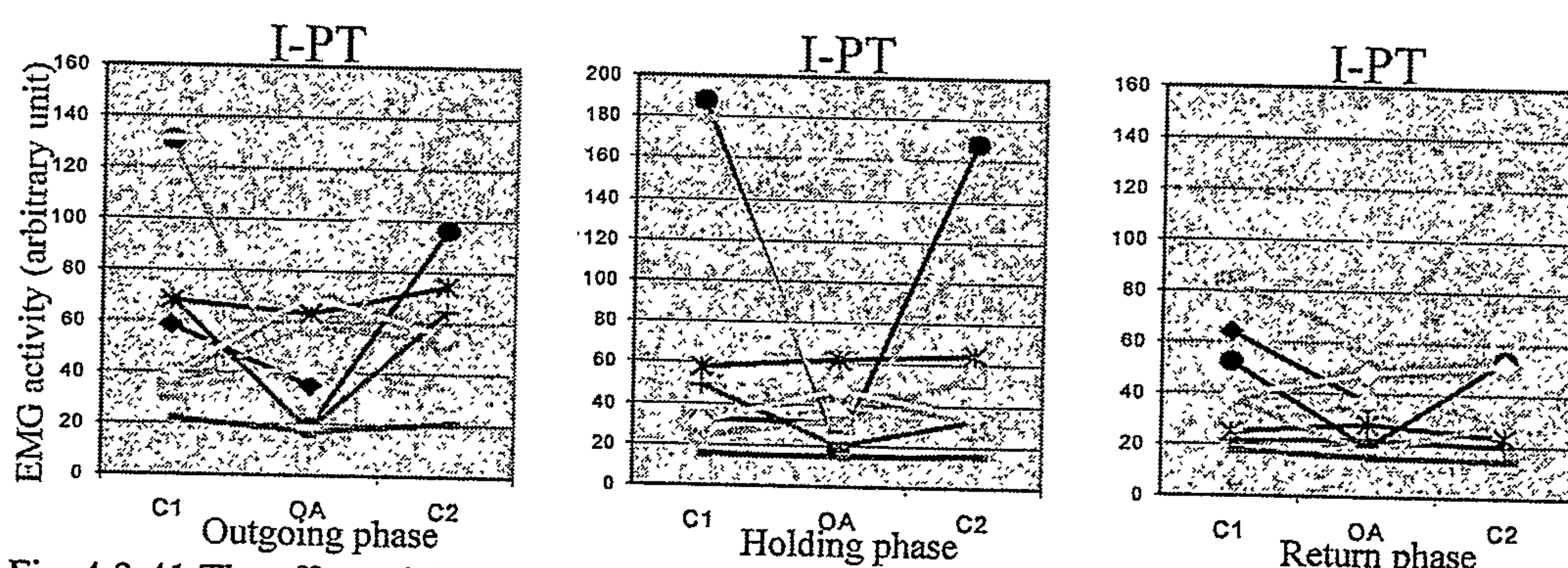


Fig. 4.3-41 The effect of the occlusal alteration on the mean EMG activity of the ipsilateral posterior temporalis of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

There was no significant difference between the mean EMG activity of the ipsilateral posterior temporalis under the three occlusal conditions in the three

phases. The effect of the occlusal alteration was variable between subjects as shown in Fig. 4.3-41.

Table 4.3-4 shows that the occlusal alteration did not change the ipsilateral posterior temporalis activity in most of the subjects and it caused a lower activity in some subjects. The sham overlay did not cause any change in the all three phases. The occlusal alteration also did not change the overall pattern of the ipsilateral posterior temporalis activity (e.g. Fig. 4.3-33).

Ipsilateral masseter

A comparison of the mean EMG activity of the ipsilateral masseter showed a significantly lower activity with the occlusal alteration in the three phases than that under the control 1 and 2 conditions. There was no significant difference between the control 1 and 2 conditions. In Fig. 4.3-42, data from all subjects showed that the EMG activity under the occlusal alteration was lower than that under the control 1 and 2 conditions.

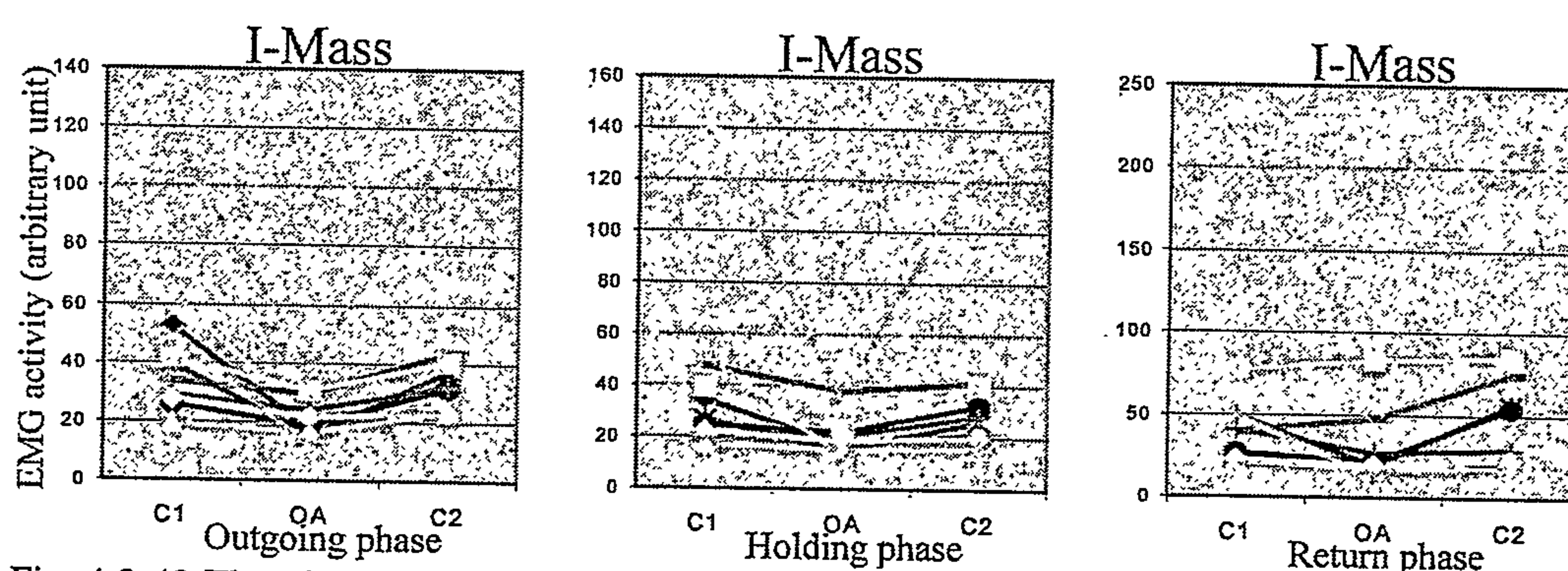


Fig. 4.3-42 The effect of the occlusal alteration on the mean EMG activity of ipsilateral masseter of each subject under three occlusal conditions is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

When subjects were analyzed individually, most showed no influence due to the occlusal alteration, whereas there was a significantly lower activity in the rest of

the subjects (Table 4.3-4). In the two sham-overlay subjects, the occlusal alteration caused a lower activity at the outgoing, holding and return phases in the same subject who also showed a lower activity in the ipsilateral anterior temporalis. In the other subject, the EMG activity was not changed at the outgoing and holding phases, and was higher in activity at the return phase under the occlusal alteration (sham overlay) condition. The qualitative assessment showed that the occlusal alteration did not change the overall pattern of the ipsilateral anterior temporalis activity (e.g. Fig. 4.3-33).

Ipsilateral submandibular muscles

There was no statistical difference between the mean EMG activity of ipsilateral submandibular muscles under three occlusal conditions in the outgoing, holding and return phases. In Fig. 4.3-43, the occlusal alteration did not cause any effect on the activity of the ipsilateral submandibular muscles in most subjects.

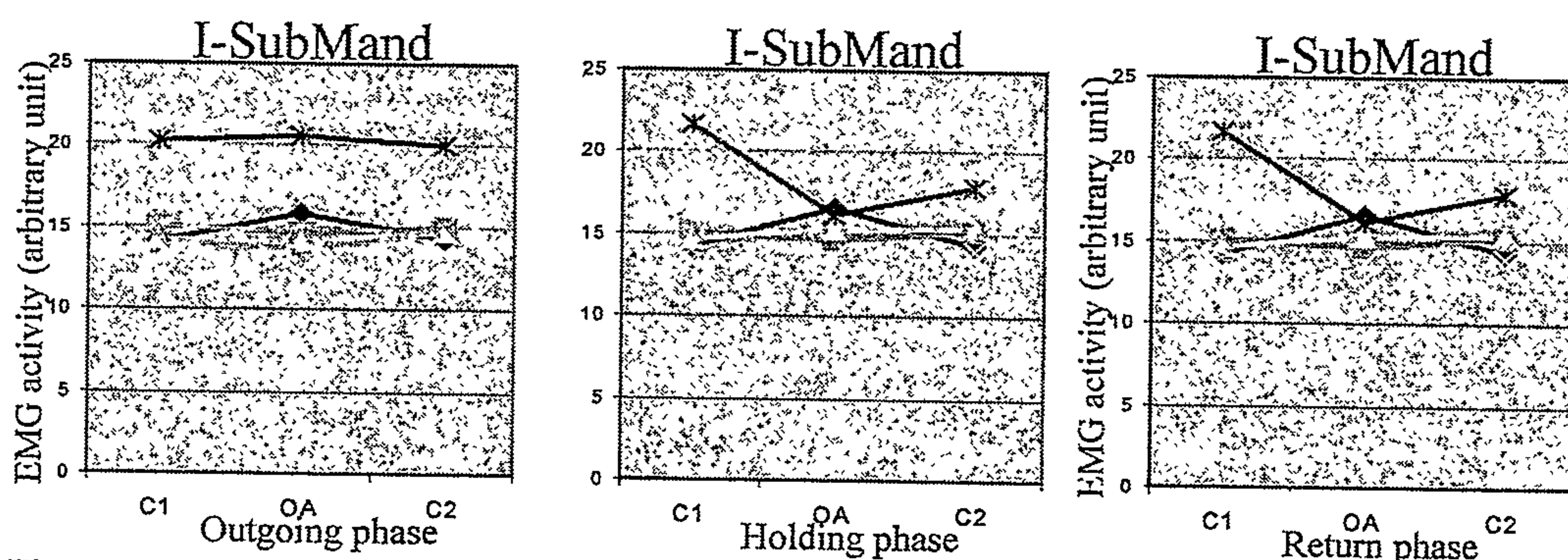


Fig. 4.3-43 The effect of the occlusal alteration on the mean EMG activity of the ipsilateral submandibular muscles of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

Table 4.3-4 shows that the occlusal alteration did not change the ipsilateral submandibular muscle activity in all except one subject. The qualitative assessment showed that the occlusal alteration did not change the overall pattern of the ipsilateral submandibular muscle activity.

4.3.2.2 Protrusion with low closing force (as control movement)

The data from 10 subjects, in whom the occlusal alteration did not cause any interference during protrusion but did so in laterotrusion, was used for the following MIPT and EMG comparison. In summary, the occlusal alteration did not cause any alteration in the activity of the recorded jaw muscles during protrusion (as a control movement). Fig. 4.3-44 shows representative mid-incisor point (MIPT) movement and raw EMG data from one trial in one subject under the three conditions during protrusion.

MIPT movement assessment

There was no significant difference for each of the mean onset and offset times of three-dimensional MIPT movements under the three conditions. The average onset (at ~2.9 s) or offset (at ~11.1 s) time was slightly later than the instructed onset (at 2.6 s) or offset (at 10.8 s) time (indicated by visual feedback).

The influence of an occlusal alteration during protrusion (as control movement)

An overall comparison of the mean EMG activity showed that the occlusal alteration did not cause any change in the activity of the recorded jaw muscles, except for the contralateral IHLP at the return phase for the entire phase analysis and the ipsilateral masseter muscle at the outgoing phase during protrusion. However, in these two muscles, the EMG activity under the control 1 condition was significantly higher than that under the occlusal alteration condition, and the EMG under the occlusal alteration condition was higher than that under the control 2 condition. Furthermore, the contralateral IHLP at the return phase (3

mm away from IP) and the ipsilateral anterior temporalis muscles at the outgoing and return phases showed that the control 1 EMG was significantly higher than the control 2 EMG, and the occlusal-alteration EMG activity level was between the control 1 and 2 activity level without significant difference. During protrusion, the occlusal alteration did not change the onset and the offset time difference between IHLP and MIPT movement (Table 4.3-7).

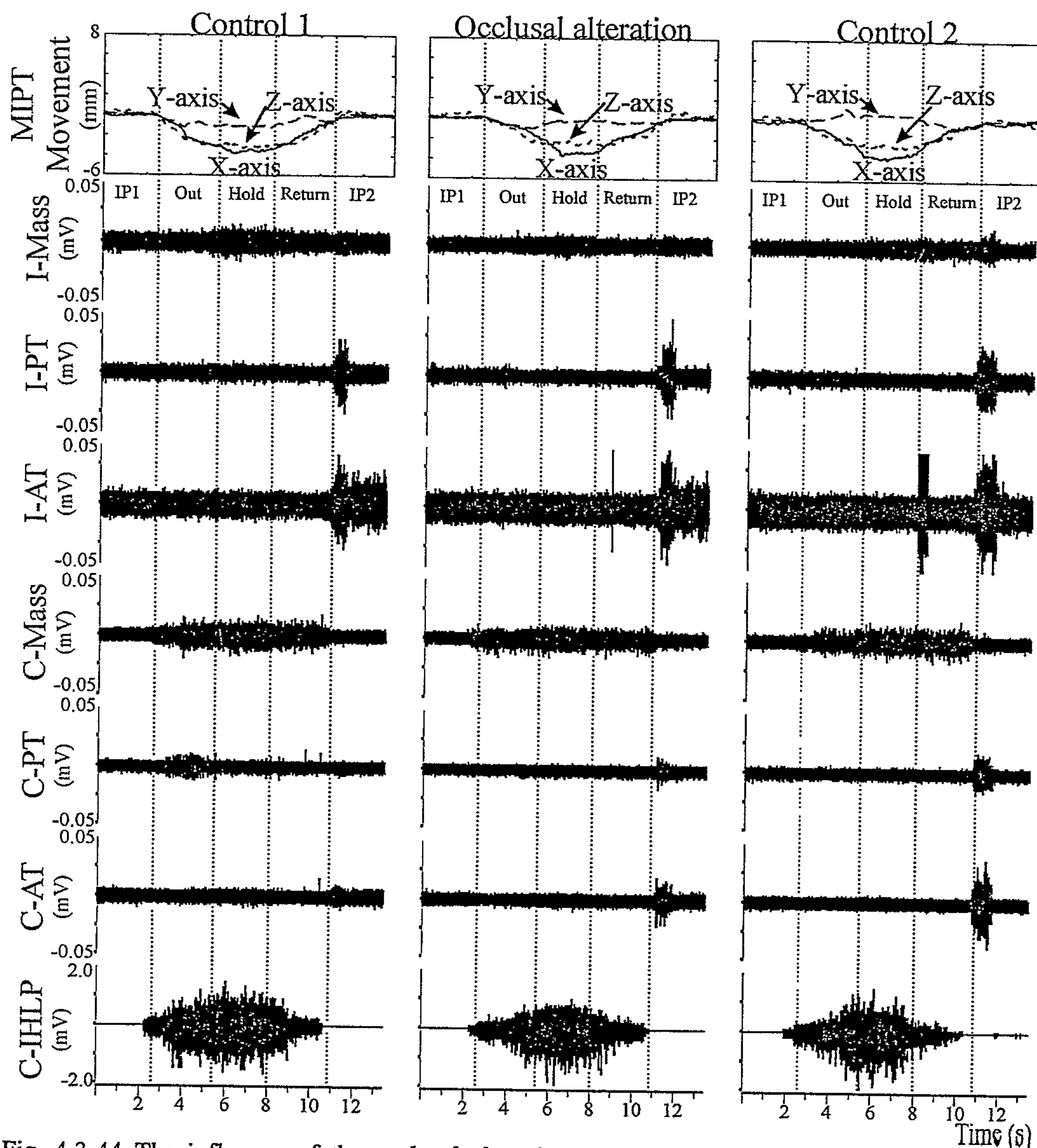


Fig. 4.3-44 The influence of the occlusal alteration on jaw muscles during protrusion at low closing force level. Examples of raw EMG activity under the control 1, occlusal alteration and control 2 conditions are displayed. Each vertical dotted line separates two phases. Each trace of muscle activity is displayed at the same amplitude under three conditions. C-: contralateral side to the occlusal alteration and the direction of laterotrusion; I-: ipsilateral side; IHLP: inferior head of lateral pterygoid; AT: anterior temporalis; PT: posterior temporalis; Mass: masseter; IP1: intercuspal position 1 phase; Out: outgoing phase; Hold: holding phase; IP2: intercuspal position 2 phase; MIPT: mid-incisor point; X-axis: antero-posterior axis; Y-axis: medio-lateral axis; Z-axis: supero-inferior axis.

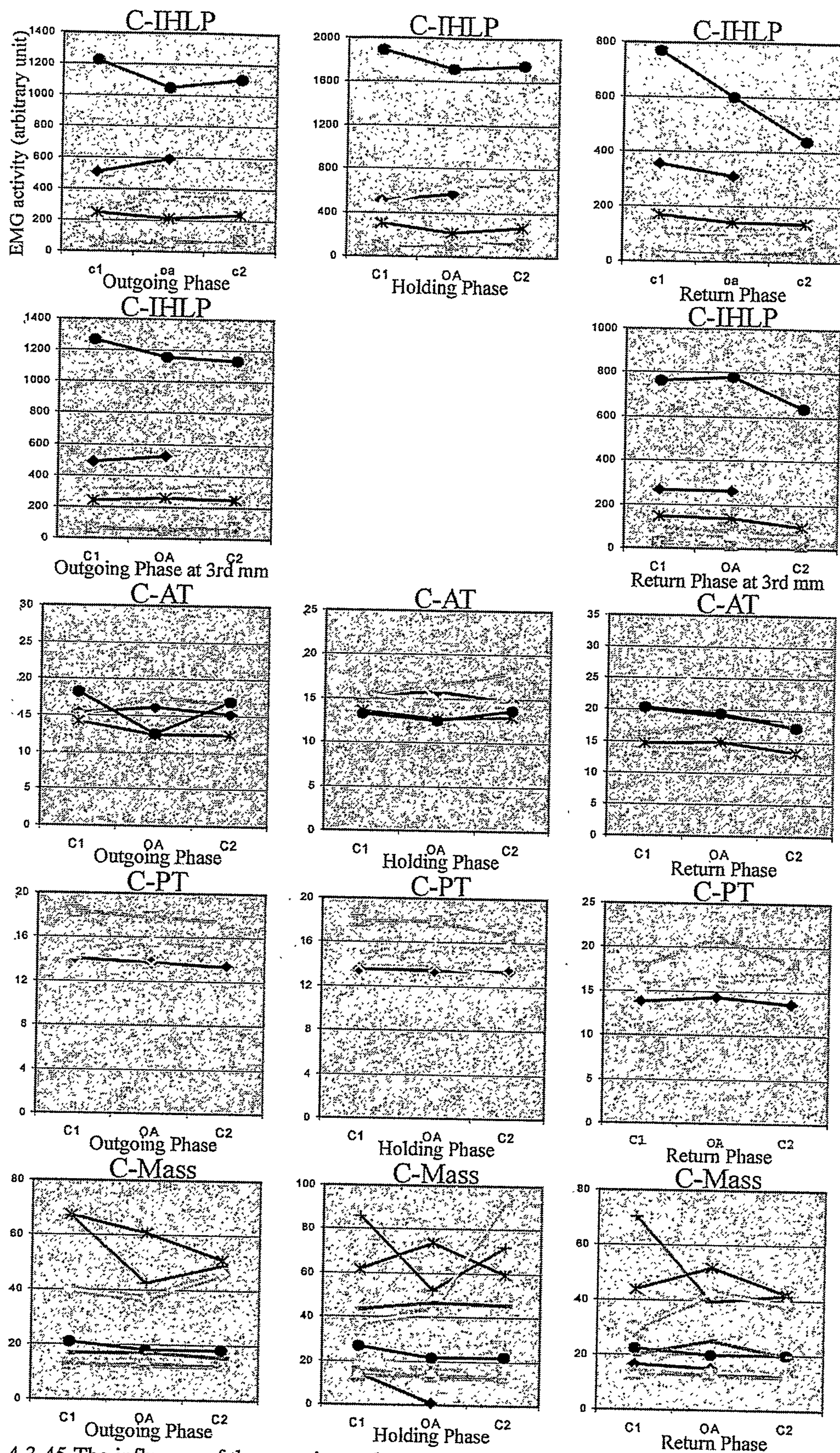


Fig. 4.3-45 The influence of the experimental occlusal alteration, which did not alter the tooth contact relation during protrusion. C-: contralateral; I-: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter; SubMand: submandibular muscles.

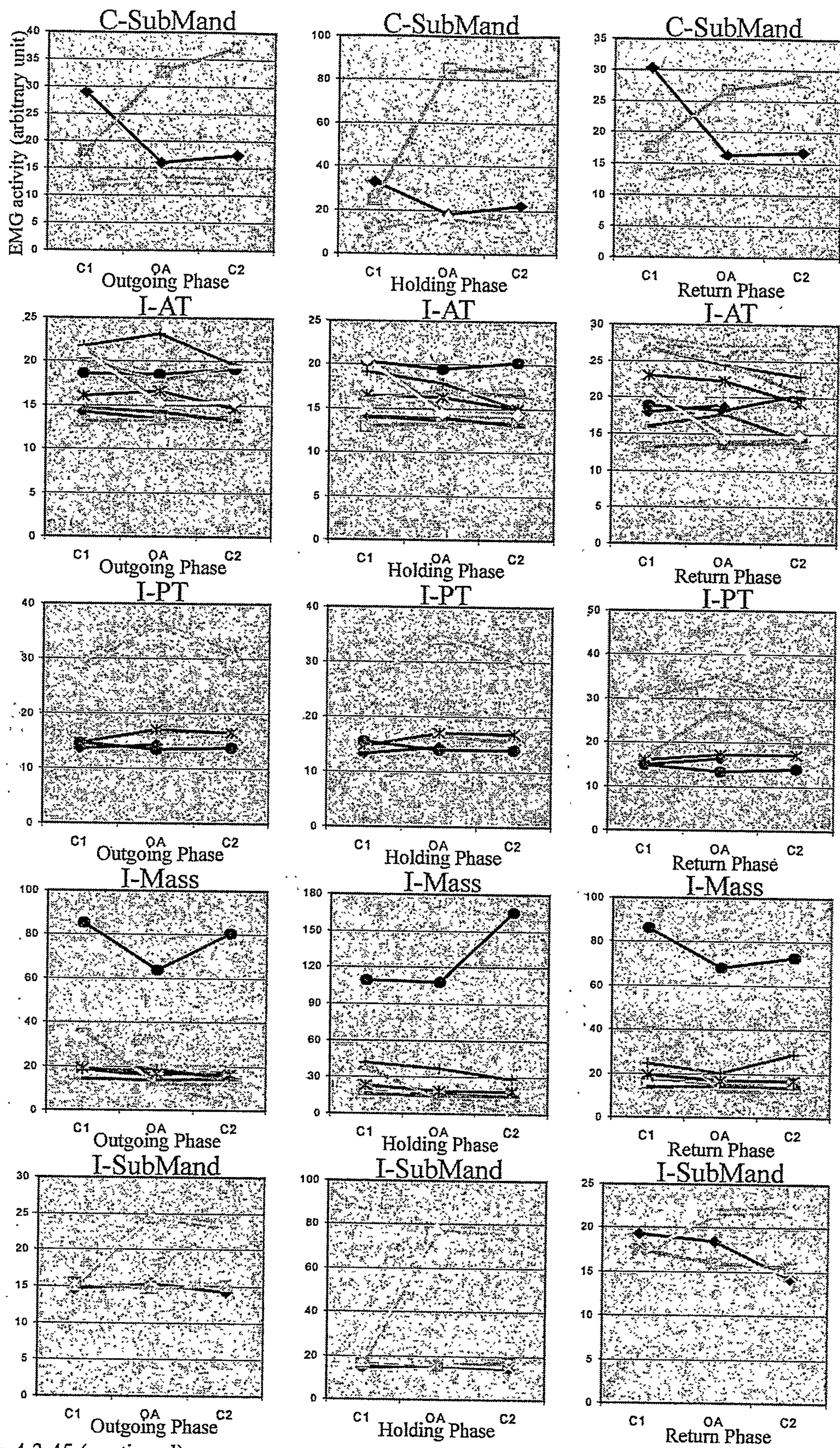


Fig. 4.3-45 (continued)

Subjects	Onset			Offset		
	Control 1	Occlusal alteration	Control 2	Control 1	Occlusal alteration	Control 2
1	-3.35	-1.57		2.29	3.8	
2	0.25	0.11	0.69	-0.1	1.5	0.99
3	-0.2	0.11	0.28	-0.31	-0.03	0.52
4	0.78	0.49	0.39	-0.01	0.59	0.81
5	0.57	0.77	0.83	0.1	-0.11	0.51
6	0.53	0.47	0.69	0.06	0.19	0
Mean $\pm$ SD	-0.24 $\pm$ 1.56	0.06 $\pm$ 0.84	0.58 $\pm$ 0.23	0.34 $\pm$ 0.97	0.99 $\pm$ 1.50	0.57 $\pm$ 0.38

Table 4.3-7 The mean onset and offset time difference between the MIPT movement and contralateral IHL activity from each subject under the three occlusal conditions during protrusion at low closing force level. Positive values indicate that, in this subject, the IHL activity started (or stopped) earlier than the MIPT displacement.

Fig. 4.3-45 shows the mean EMG activity of jaw muscles from each subject under three conditions. The results show that, in most of the subjects, the EMG activity was not influenced by the occlusal alteration used in this study or showed a progressive decrease from one condition to the next. This progressive change together with the overall comparison raise the possible issue of other factors, such as muscle fatigue, influencing the EMG recordings.

A comparison between the three conditions within individual subjects (Table 4.3-8) showed that the occlusal alteration used in this study did not alter jaw muscle activity during protrusion in most of the subjects, especially when the EMG activity under the control 2 condition was taken into consideration.

Qualitatively, the occlusal alteration used in this study did not alter the overall pattern of muscle activity during protrusion (e.g. Fig. 4.3-44). In addition, an assessment of the IHL activity at each mm of MIPT displacement showed that there was no effect of the occlusal alteration (e.g. Fig. 4.3-46).

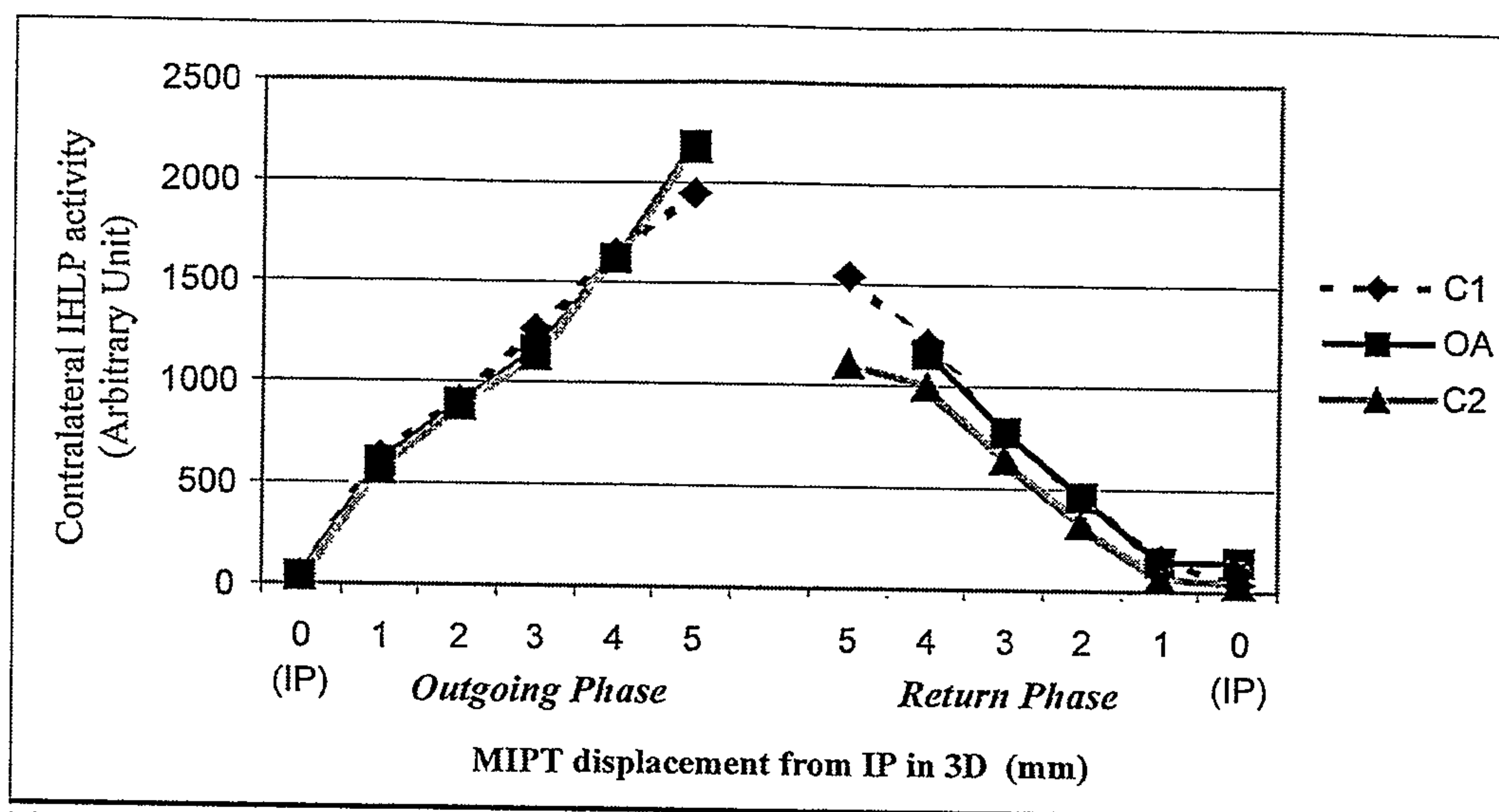


Fig. 4.3-46 The influence of the occlusal alteration on the contralateral IHL P activity at each mm of MIPT movement (with normalizing method one) during protrusion. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

(A) Outgoing phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	1	5 (2)			5 (1)			5 (1)	
	entire	2	4 (2)		1	4 (1)			5 (1)	
C_AT		1	4 (2)	2	1	6 (1)			7 (1)	
C_PT		1	3 (2)		1	3 (1)			4 (1)	
C_MASS			8 (2)	2		8 (1)	1		9 (1)	
C_SubMand			2	1		2	1		3	
I_AT			7 (2)	3		8 (1)	1		9 (1)	
I_PT		1	4 (1)	1	1	3 (1)	1		5 (1)	
I_MASS			6 (1)	3 (1)		7 (1)	2		9 (1)	
I_SubMand			4			4			4	

(B) Holding phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP										
	entire	3 (1)	1 (1)	2	1	2 (1)	2	1	3 (1)	1
C_AT		1	5 (2)	1		6 (1)	1		7 (1)	
C_PT		1	3 (2)			4 (1)			4 (1)	
C_MASS			7 (2)	3		7 (1)	2		9 (1)	
C_SubMand		1	1	1	1	1	1		3	
I_AT		2	6 (2)	2	1	8 (1)			9 (1)	
I_PT		1	4 (1)	1	1	3 (1)	1		5 (1)	
I_MASS			6 (1)	3 (1)		8 (1)	1		9 (1)	
I_SubMand		1	3		1	3			4	

(C) Return phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm		4 (2)	2		3 (1)	2		5 (1)	
	entire		5 (2)	1		5 (1)			5 (1)	
C_AT		1	6 (2)			7 (1)			7 (1)	
C_PT		(1)	4 (1)			4 (1)			4 (1)	
C_MASS			7 (2)	3		8 (1)	1		9 (1)	
C_SubMand		1	1	1	1	1	1	1	2	
I_AT		1	8 (2)	1		8 (1)	1		9 (1)	
I_PT		1	4 (1)	1	1	3 (1)	1	1	4 (1)	
I_MASS			7 (1)	2 (1)		9 (1)			9 (1)	
I_SubMand			4			4			4	

Table 4.3-8 A summary of the influence of the occlusal alteration on jaw-muscle EMG activity at the (A) outgoing, (B) holding and (C) return phases within each subject during protrusion. The numbers indicate the number of subjects who showed a statistically significantly higher (S/S higher) activity, no significant influence (no S/S), or significantly lower (S/S lower) activity under the occlusal alteration. The number in brackets is the results of the two sham overlay subjects. The first row of C_IHLP in (A) and (C) shows the comparison between EMG activity at 3 mm away from intercuspal position at the outgoing and return phases (with normalizing method one), respectively, and the second row shows the comparison between the EMG of the entire phase. Criterion 1, 2 and 3 refer to analyzes performed under progressively more stringent criteria (see Methods). In one occlusal-alteration subject and one sham-overlay subject, the EMG activity under the control 2 condition was not recorded, therefore, their data was not included in Criterion 2 and 3. C_: contralateral; I_: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter; SubMand: submandibular muscles.

4.3.2.3 Laterotrusion with low closing force at slow speed

Generally, in 14 subjects, the occlusal alteration caused a significantly lower activity in the ipsilateral jaw-closing muscles at the outgoing and holding phases, whereas there was no significant influence on the contralateral jaw muscles during slow laterotrusion with low closing force. The comparison within individual subjects showed that most subjects had a significant change due to the occlusal alteration, however, this change could be significantly higher or lower.

Fig. 4.3-47 shows an example trial from one subject under each condition.

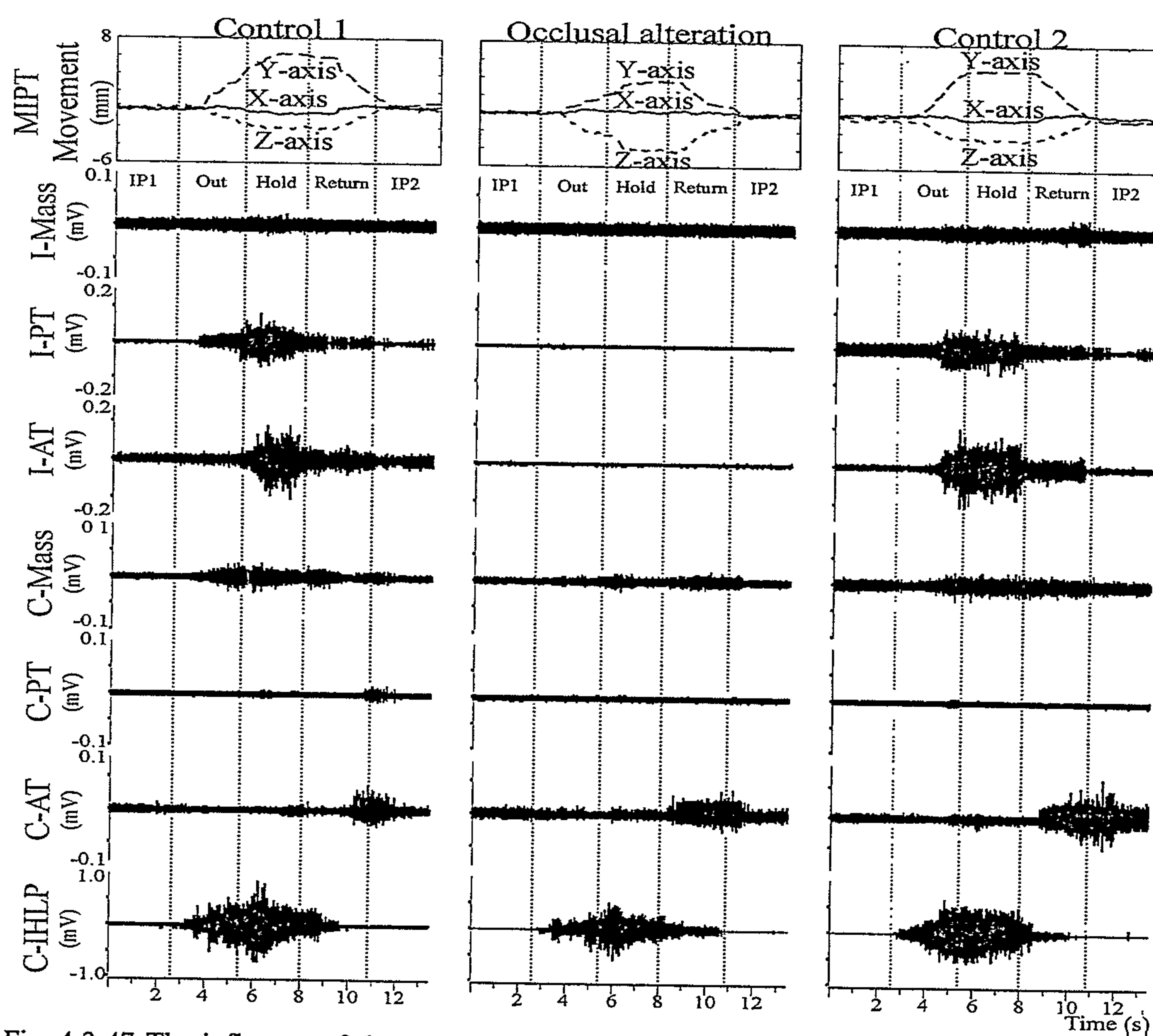


Fig. 4.3-47 The influence of the occlusal alteration on jaw muscles during slow laterotrusion at low closing force level. Examples of raw EMG activity under the control 1, occlusal alteration and control 2 conditions are displayed. Each vertical dotted line separates two phases. Each trace of muscle activity is displayed at the same amplitude under three conditions. C-: contralateral side to the occlusal alteration and the direction of laterotrusion; I-: ipsilateral side; IHLP: inferior head of lateral pterygoid; AT: anterior temporalis; PT: posterior temporalis; Mass: masseter; IP1: intercusp position 1 phase; Out: outgoing phase; Hold: holding phase; IP2: intercusp position 2 phase; MIPT: mid-incisor point; X-axis: antero-posterior axis; Y-axis: medio-lateral axis; Z-axis: supero-inferior axis.

(A) Outgoing phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	2	5 (2)	3	1	5 (1)	3		7 (1)	2
	entire	3	5 (1)	2 (1)	2	5	2 (1)	1	8	(1)
C_AT		(1)	10 (1)	1		10 (1)	1		11 (1)	
C_PT		2	2 (2)	2	2	2 (1)	2		5 (1)	1
C_MASS		1	9 (1)	5 (1)	1	10	3 (1)		14 (1)	
C_SubMand			5	1		6			6	
I_AT		1	5	9 (2)		6 (1)	8		8 (1)	6
I_PT			3	6 (1)		2 (1)	6		3 (1)	5
I_MASS			7	7 (2)		9 (1)	5		12 (1)	2
I_SubMand		1	4	1	1	5		1	5	

(B) Holding phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	entire	2	4 (2)	4	2	3 (1)	4	1	6 (1)	2
		1 (1)	8 (1)	2	1	8 (1)	2	1	10 (1)	
C_PT		1	3 (2)	2	1	3 (1)	2	1	4 (1)	1
C_MASS			7 (1)	8 (1)		9	5 (1)		11 (1)	3
C_SubMand		2	1	3	2	4		2	4	
I_AT		1	3	11 (2)		5 (1)	9		7 (1)	7
I_PT			3	6 (1)		2 (1)	6		6 (1)	2
I_MASS		1	4	9 (2)	1	5 (1)	8		8 (1)	6
I_SubMand			5	1		6			6	

(C) Return phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	5	1 (2)	4	5	1 (1)	3	5	3 (1)	1
	entire	3	1 (1)	6 (1)	3	5 (1)	1	3	6 (1)	
C_AT		1	9 (2)	1	1	9 (1)	1		10 (1)	1
C_PT		(1)	4 (1)	2		4 (1)	2		6 (1)	
C_MASS		1	8 (1)	6 (1)	1	9	4 (1)	1	13 (1)	
C_SubMand		2	2	2	2	4			6	
I_AT		1	7 (1)	7 (1)		9 (1)	5		12 (1)	2
I_PT		1	4	4 (1)	1	3 (1)	4	1	3 (1)	4
I_MASS			9	5 (2)		10 (1)	4		13 (1)	1
I_SubMand			6			6			6	

Table 4.3-9 A summary of the influence of the occlusal alteration on jaw-muscle EMG activity at the (A) outgoing, (B) holding and (C) return phases within each subject during slow laterotrusion at low closing force. The numbers indicate the number of subjects who showed a statistically significantly higher (S/S higher) activity, no significant influence (no S/S), or significantly lower (S/S lower) activity under the occlusal alteration. The number in brackets is the results of the two sham overlay subjects. The first row of C_IHLP in (A) and (C) shows the comparison between EMG activity at 3 mm away from intercuspal position at the outgoing and return phases (with normalizing method one), respectively, and the second row shows the comparison between the EMG of the entire phase. Criterion 1, 2 and 3 refer to analyzes performed under progressively more stringent criteria (see Methods). In one occlusal-alteration subject and one sham-overlay subject, the EMG activity under the control 2 condition was not recorded, therefore, their data was not included in Criterion 2 and 3. C_: contralateral; I_: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter; SubMand: submandibular muscles.

MIPT movement assessment

There was no significant difference for each of the mean onset and offset times of three-dimensional MIPT movements between the three conditions for all subjects. The average onset (at ~2.8 s) or offset (at ~11.0 s) time was slightly later than the instructed onset (at 2.6 s) or offset (at 10.8 s) time (indicated by visual feedback).

Contralateral inferior head of the lateral pterygoid muscle

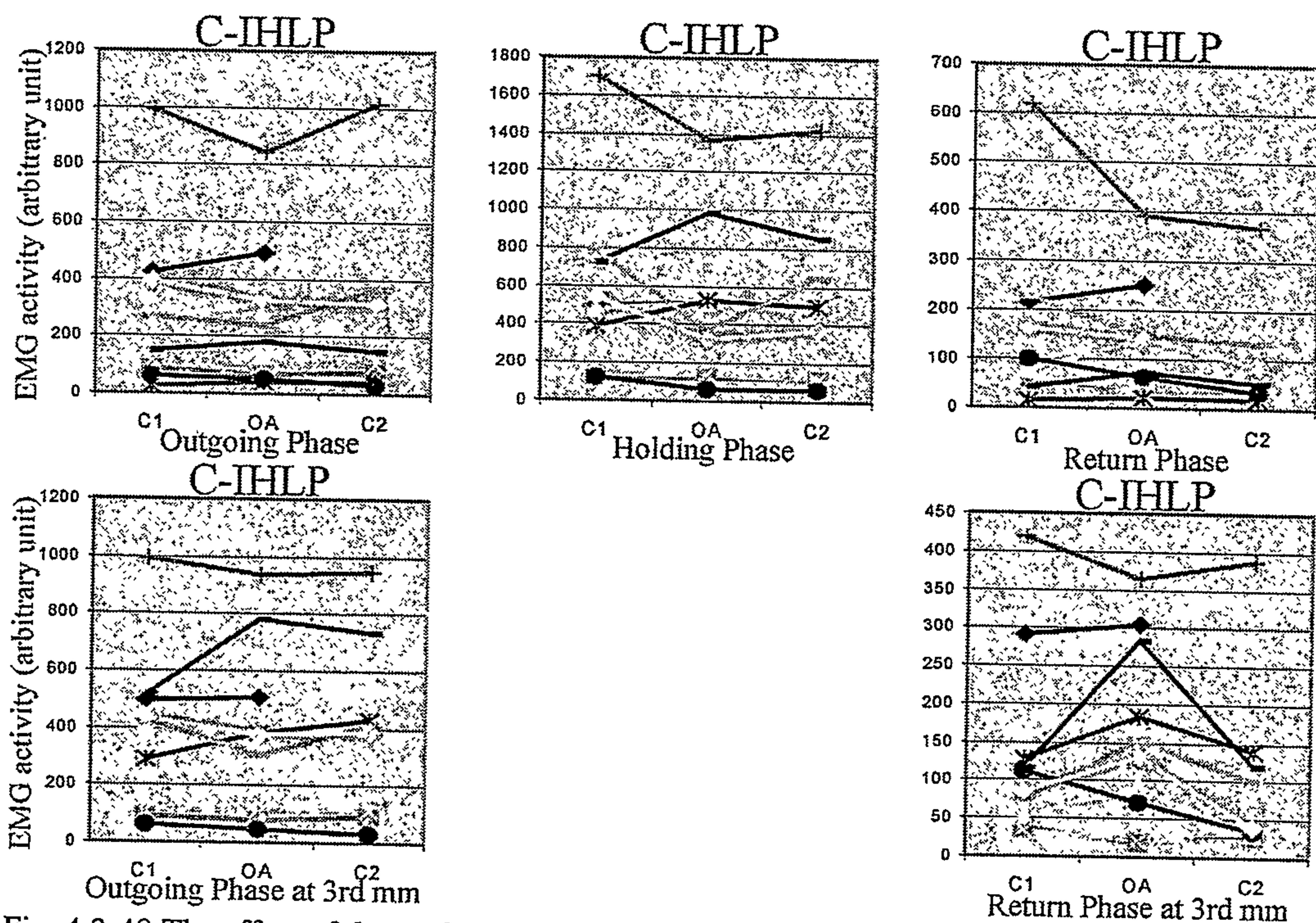


Fig. 4.3-48 The effect of the occlusal alteration on the mean EMG activity of contralateral IHLP of each subject is displayed. (A) Mean EMG activity of entire phases. (B) Mean EMG activity when MIPT was 3 mm away from intercuspal position. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

Overall comparison

For all 10 subjects, with IHLP recordings available, a comparison of the mean EMG activity of contralateral IHLP during slow laterotrusion with low closing force showed that there was no significant difference between the three

conditions for all three phases in both comparisons of the mean EMG activity of entire phase and at the 3rd mm of MIPT displacement. Fig. 4.3-48 showed that the effect of the occlusal alteration during low closing force was qualitatively more variable at the return phase than that with high closing force (Fig. 4.3-34). During laterotrusion with low closing force, the occlusal alteration did not significantly alter the onset and offset time difference between the IHLP activity and the MIPT movement (Table 4.3-10).

Subjects	Onset			Offset		
	Control 1	Occlusal alteration	Control 2	Control 1	Occlusal alteration	Control 2
1	0.38	0.21		0.52	0.70	
2	0.45	0.51	0.54	0.00	0.90	0.73
3	-0.41	-0.15	0.11	0.21	-0.20	0.93
4	0.56	0.24	0.31	0.19	0.21	0.47
5	-0.27	-0.11	-0.18	2.28	1.28	2.23
6	0.13	-0.62	-0.29	0.32	0.60	1.48
7	0.64	0.39	0.80	0.16	0.30	0.33
8	0.05	0.29	0.11	1.36	0.50	1.69
9	0.30	0.70	0.38	1.07	0.43	0.77
10	0.40	0.59	0.41	-0.20	-0.43	0.43
Mean $\pm$ SD	0.22 $\pm$ 0.35	0.21 $\pm$ 0.40	0.24 $\pm$ 0.34	0.59 $\pm$ 0.76	0.43 $\pm$ 0.50	1.01 $\pm$ 0.65

Table 4.3-10 The mean onset and offset time difference between the MIPT movement and contralateral IHLP activity from each subject under the three occlusal conditions during slow laterotrusion at low closing force level. Positive values indicate that, in this subject, the IHLP activity started (or stopped) earlier than the MIPT displacement.

Individual comparison

When subjects were analyzed individually (shown in Table 4.3-9), the occlusal alteration did appear to cause a significant change in contralateral IHLP activity in most subjects, at the holding and return phases. However, this change could be a significantly higher activity in some subjects, but a significant lower activity in other subjects. These non-uniform effects between subjects could explain why the comparison of the mean EMG activity from all subjects showed no significant difference.

In addition, the effect of the occlusal alteration on the IHLP could be different between two closing force levels in some subjects. In three subjects, the influence of the occlusal alteration on the IHLP activity shifted from a significantly higher activity at the high closing force to a significantly lower activity at the low closing force in one of the three phases. Whereas, in the other seven subjects, there was a similar effect under the occlusal alteration or a slight change from a significant effect to a non-significant effect.

Furthermore, different normalizing methods could show different results for the same data. If only the data of the control 1 and occlusal alteration were taken into consideration (as Criterion 1 in Table 4.3-9), two subjects showed a significantly higher activity at the 3rd mm of MIPT displacement from IP during the return phase but a significantly lower activity for the entire return phase.

In the additional subject where the occlusal alteration caused an increased vertical dimension at intercuspal position and a smaller inclination during laterotrusion, the IHLP activity under the occlusal alteration was significantly lower than under the control 1 condition. In the two sham-overlay subjects, the sham overlay did not cause any change in IHLP, except at the outgoing phase.

Influence of an occlusal alteration on IHLP activity associated with the electrode recording sites

According to the CT scan verification data (available in eight subjects), the intramuscular electrodes were located within the medial half of the contralateral IHLP: five in the upper quarter and three in the lower. The data in Table 4.3-11

provide suggestive evidence that the infero-medial quarter was more likely to have a significantly lower activity, especially at the outgoing and holding phases. However, more data would be needed in the future studies.

Position	Subject	Outgoing	Holding	Return
Supero-medial	01	↑ (X)	↑	↑
	02	X	X	X (↓)
	03	X (↓)	↓	X (↑)
	04	X	X	↑
	05	↑ (X)	X	X
Infero-medial	06	↓	↓	X (↑)
	07	↓	X	↓
	08	X	↓	X (↓)

Table 4.3-11 The influence of the occlusal alteration on the contralateral IHLP activity associated with the electrode recording site in eight subjects where electrode position was verified by CT scan data. Position column indicates that, in these subjects, the recording sites were located in the superior- (or infero-) medial quarter of the IHLP. In the right three columns, the influence of the occlusal alteration on the IHLP during each entire phase is shown (based on Criterion 2, except Subject 05, in which the Criterion 1 result is shown due to the lack of the control 2 recordings). The symbols in brackets indicate the results at the 3-mm MIPT displacement, if differing to the results of the entire phase. Subjects in each quarter are listed in an arbitrary order. ↑: significantly higher due to the occlusal alteration; X: no significant changes; ↓: significantly lower.

Qualitative comparison

A qualitative assessment, including raw data comparison (e.g. Fig. 4.3-47) and superimposed averaged EMG plots under the three conditions, showed that the occlusal alteration did not change the overall pattern of the contralateral IHLP activity. As in the high closing force level, the comparison between the EMG activity at each mm of MIPT displacement showed that the effect of the occlusal alteration did not increase or decrease progressively at low closing force while the MIPT was further away from the intercuspal position. The most predominant difference appeared to be at 2 – 4 mm away from the intercuspal position. Fig. 4.3-49 shows examples of the influence of the occlusal alteration from two subjects in comparison with the control 1 condition: subject A showed a

significantly higher and subject B showed a significantly lower activity under the influence of the occlusal alteration.

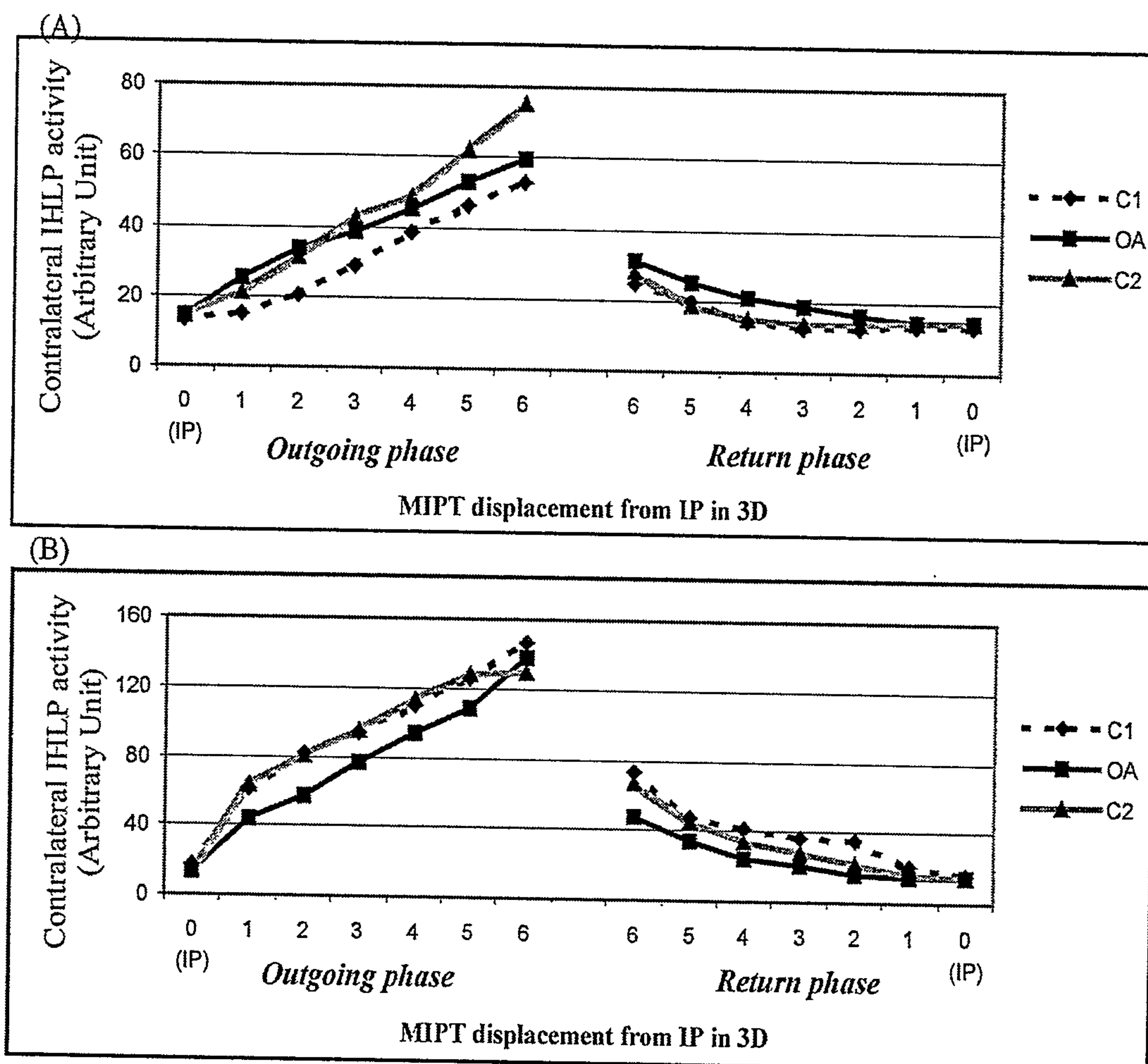


Fig. 4.3-49 Examples from two subjects of the influence of the occlusal alteration on contralateral IHLP activity at each mm of MIPT movement (with normalizing method one) during slow laterotrusion at low closing force. The IHLP activity under the control 2 condition in (A) did not return to the control 1 level. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

Contralateral anterior and posterior temporalis and masseter muscles

For all subjects, a comparison of the mean EMG activity of the contralateral anterior and posterior temporalis and masseter muscles during slow laterotrusion with low force did not show any significant alteration of EMG activity except for the contralateral masseter at the holding phase. At the holding phase, the control 1 masseter activity was significantly higher than the masseter activity under the occlusal alteration and control 2 conditions, and there was no difference between

the activity of the contralateral masseter under the occlusal alteration and control 2 conditions. As shown in Fig. 4.3-50, the effect of the occlusal alteration on the EMG activity of the contralateral anterior and posterior temporalis and masseter was variable between subjects.

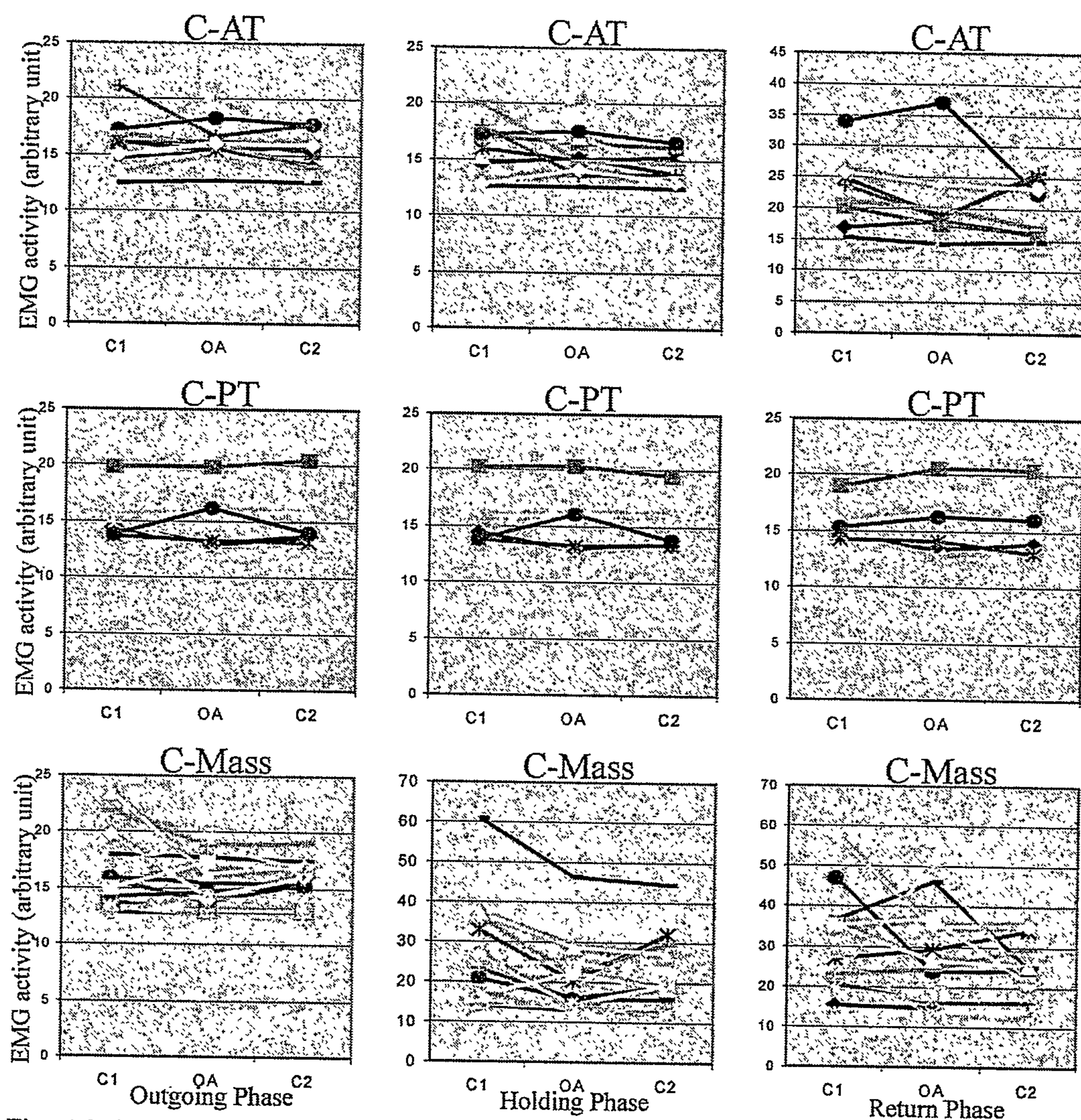


Fig. 4.3-50 The effect of the occlusal alteration on the mean EMG activity of contralateral anterior (C-AT) and posterior temporalis (C-PT) and masseter (C-Mass) of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

The comparison of the EMG activity of these three muscles under the three conditions within individual subjects (Table 4.3-9) showed that the occlusal alteration did not cause significant influences in most of the subjects, especially when the control 2 recordings were taken into consideration. The sham overlay did not alter the contralateral anterior and posterior temporalis and masseter

activity, especially when the control 2 data were taken into consideration. The qualitative assessment showed that the overall pattern of these three muscles during slow laterotrusion with low force was not changed due to the occlusal alteration (e.g. Fig. 4.3-47).

Ipsilateral anterior and posterior temporalis and masseter muscles

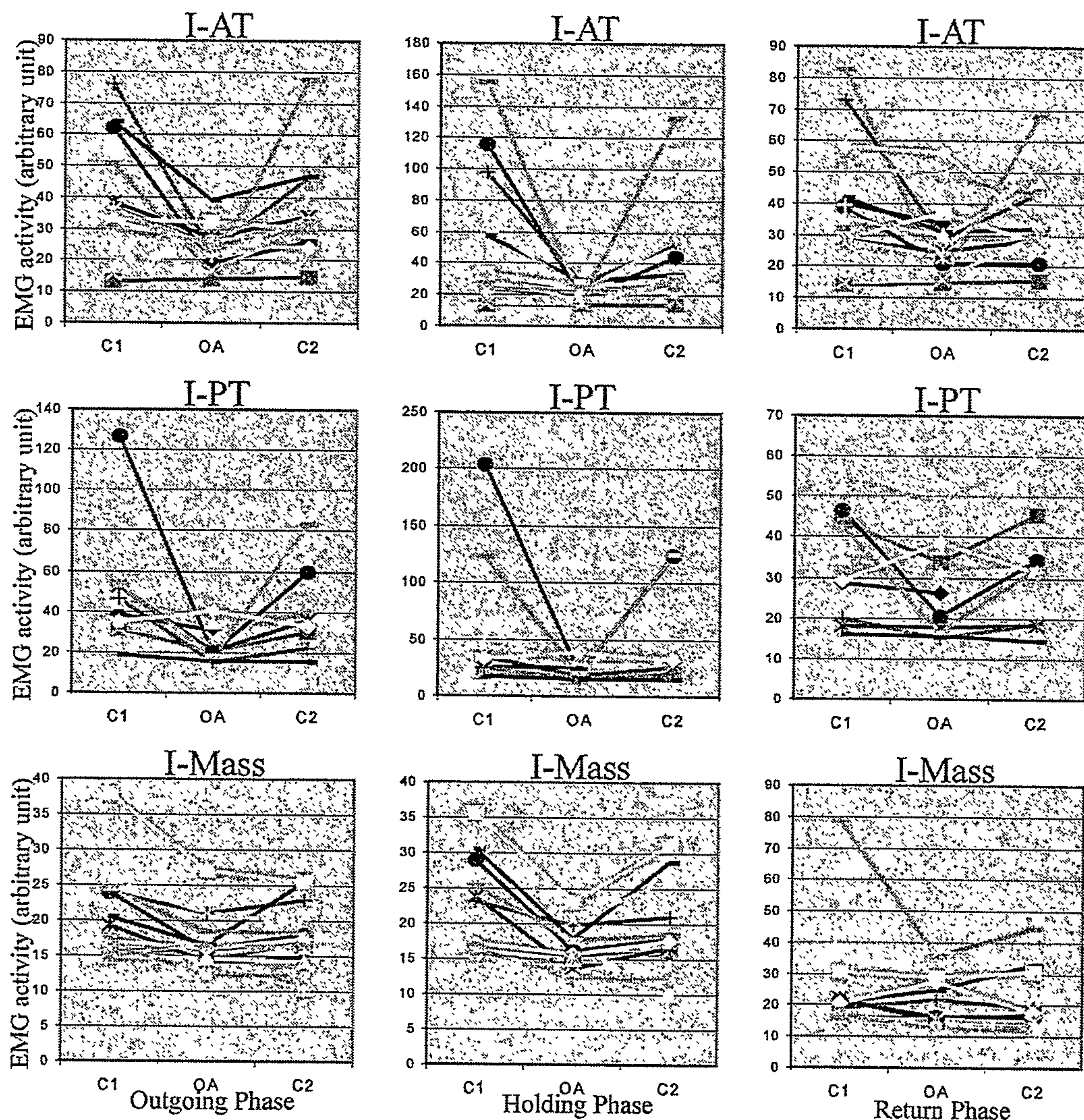


Fig. 4.3-51 The effect of the occlusal alteration on the mean EMG activity of ipsilateral anterior (I-AT) and posterior temporalis (I-PT) and masseter (I-Mass) of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

In all subjects, a comparison of the mean EMG activity of ipsilateral anterior and posterior temporalis and masseter muscles during slow laterotrusion with low force showed a statistically lower activity at the outgoing and holding phases in

all three muscles and at the return phase in ipsilateral anterior temporalis. In addition, at the outgoing and holding phases, the ipsilateral anterior temporalis EMG under the occlusal alteration was also significantly lower than that under the control 2 condition, and there was no difference in activity between the two control conditions. In Fig. 4.3-51, the EMG activity under the occlusal alteration was lower than that under the control 1 and 2 conditions.

The comparison within individual subjects (Table 4.3-9) demonstrated that most of the subjects showed a significantly lower activity in the ipsilateral anterior and posterior temporalis and masseter muscles due to the occlusal alteration, especially at the outgoing and holding phases. In addition, the ipsilateral anterior and posterior temporalis and masseter muscles were qualitatively more likely to have a significantly lower activity than the contralateral anterior and posterior temporalis and masseter muscles. In the two sham overlay subjects, the EMG of the ipsilateral anterior and posterior temporalis and masseter muscles under the occlusal alteration (sham overlay) was significantly lower than that under the control 1 condition. However, if the control 2 data was also considered, there were no significant changes due to the sham overlay. The qualitative assessment showed no change in the overall pattern due to the occlusal alteration, except in two subjects. In these two subjects, the ipsilateral anterior and posterior temporalis showed an increase at the outgoing phase, a peak at the holding phase and then a return under the control 1 and 2 conditions, but the EMG activity remained at the level of the IP1 phase throughout the movement under the influence of the occlusal alteration (e.g. Fig. 4.3-47).

Bilateral submandibular muscles

The comparison of the mean EMG activity of the bilateral submandibular muscles during slow laterotrusion with low force did not show any significant alteration in EMG activity except for the ipsilateral submandibular muscles at the return phase which showed a significantly higher activity under the occlusal alteration than that under the control 1 and 2 conditions. In Fig. 4.3-52, the influence of the occlusal alteration on the contralateral submandibular muscles was variable between subjects. In the ipsilateral submandibular muscles, the influence of the occlusal alteration was relatively smaller than other jaw muscles, although it showed a overall statistically higher activity due to the occlusal alteration.

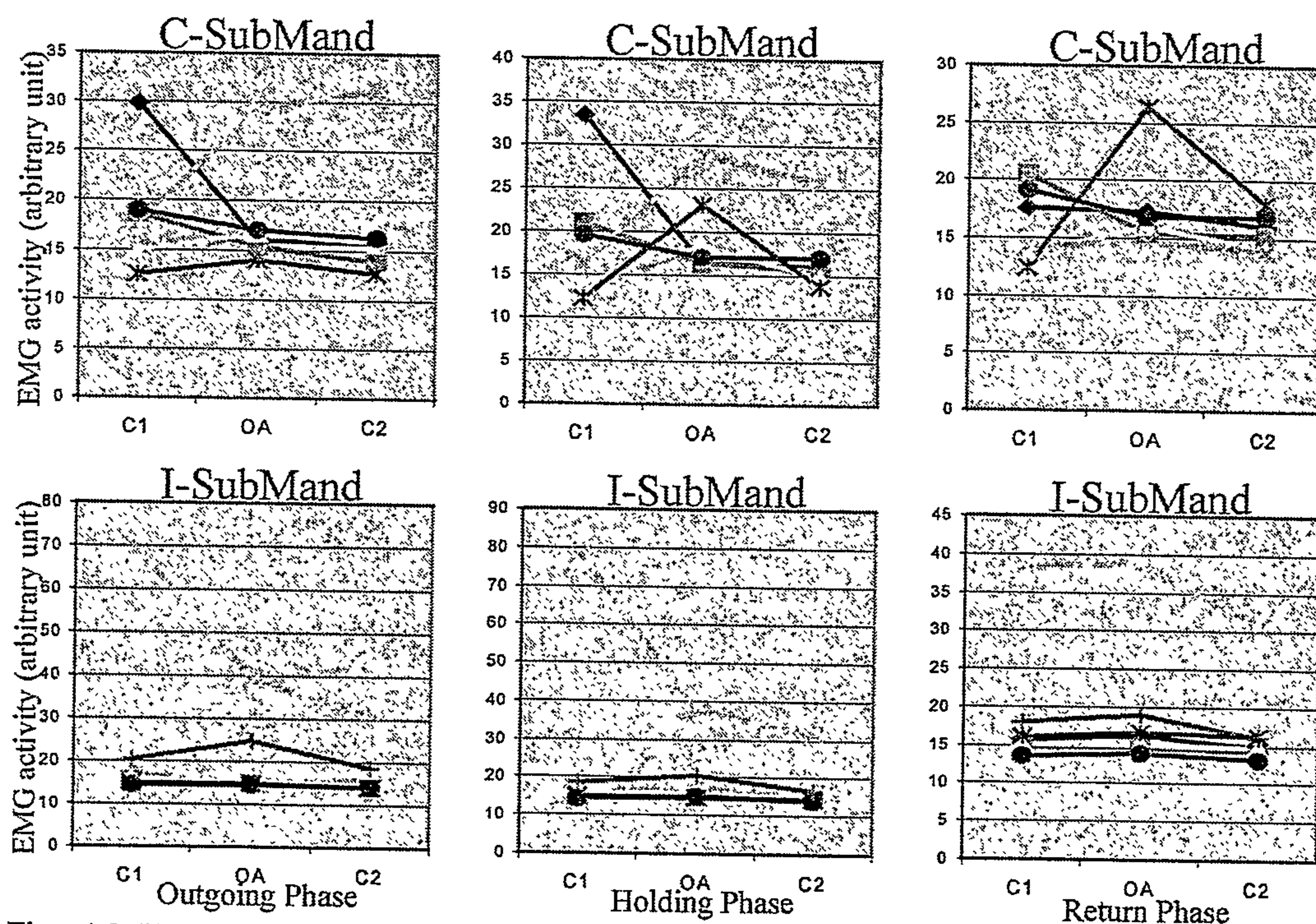


Fig. 4.3-52 The effect of the occlusal alteration on the mean EMG activity of bilateral submandibular muscles of each subject is displayed. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

In Table 4.3-9, most of the subjects showed no significant change of the activity of the bilateral submandibular muscles under the influence of the occlusal alteration, especially when the control 2 data were considered.

Possible prolonged effects of occlusal alteration

The overall comparison of the mean EMG activity showed a statistically significant difference between the two control conditions in the ipsilateral anterior temporalis (holding phase) and masseter (holding and return phases) and contralateral masseter (outgoing and holding phases) muscles. In Fig. 4.3-48, -50 and -51, the mean EMG activity level under the control 2 condition did not fully return to those levels under the control 1 condition in some muscles of some subjects. This suggests a possible prolonged effect of the occlusal alteration.

4.3.2.4 Laterotrusion with low closing force at fast speed

MIPT movement assessment

There was no significant difference between the mean onset and offset times of three-dimensional MIPT movements under the three conditions from all five subjects during fast laterotrusion with low closing force. The average onset (at ~2.3 s) or offset (at ~6.4 s) time was slightly later than the instructed onset (at 2.15 s) or offset (at 6.3 s) time (indicated by visual feedback).

The influence of occlusal alteration on jaw muscles during fast movement

The comparison of the mean activity during fast laterotrusion with low closing force showed that there was no significant difference between the three occlusal conditions in all muscles, except the contralateral masseter at the holding phase and the ipsilateral posterior temporalis at the outgoing phase, in which the EMG under the occlusal alteration condition was lower than the control 1 and 2 conditions with significant difference between the control 1 and occlusal alteration conditions. The data for individual subjects in Fig. 4.3-53 showed that the effect of the occlusal alteration on the contralateral jaw muscles during fast laterotrusion was quite variable, as was observed during the slow laterotrusion with low closing force. In the ipsilateral anterior and posterior temporalis and the masseter muscles, the occlusal alteration mainly caused a lower activity, especially at the outgoing and holding phases.

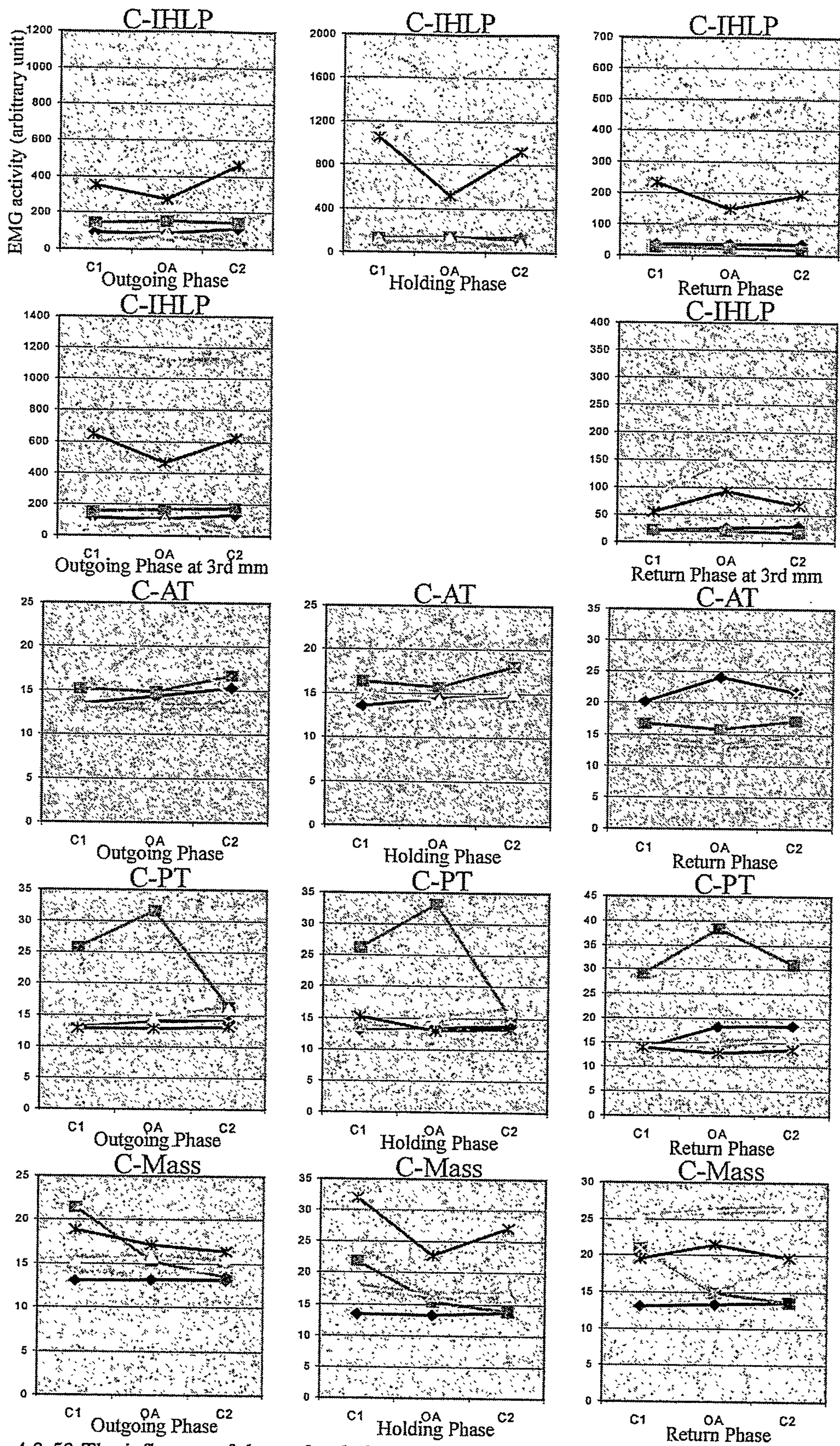


Fig. 4.3-53 The influence of the occlusal alteration on jaw muscles during fast laterotrusion with low closing force. C-: contralateral; I-: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter.

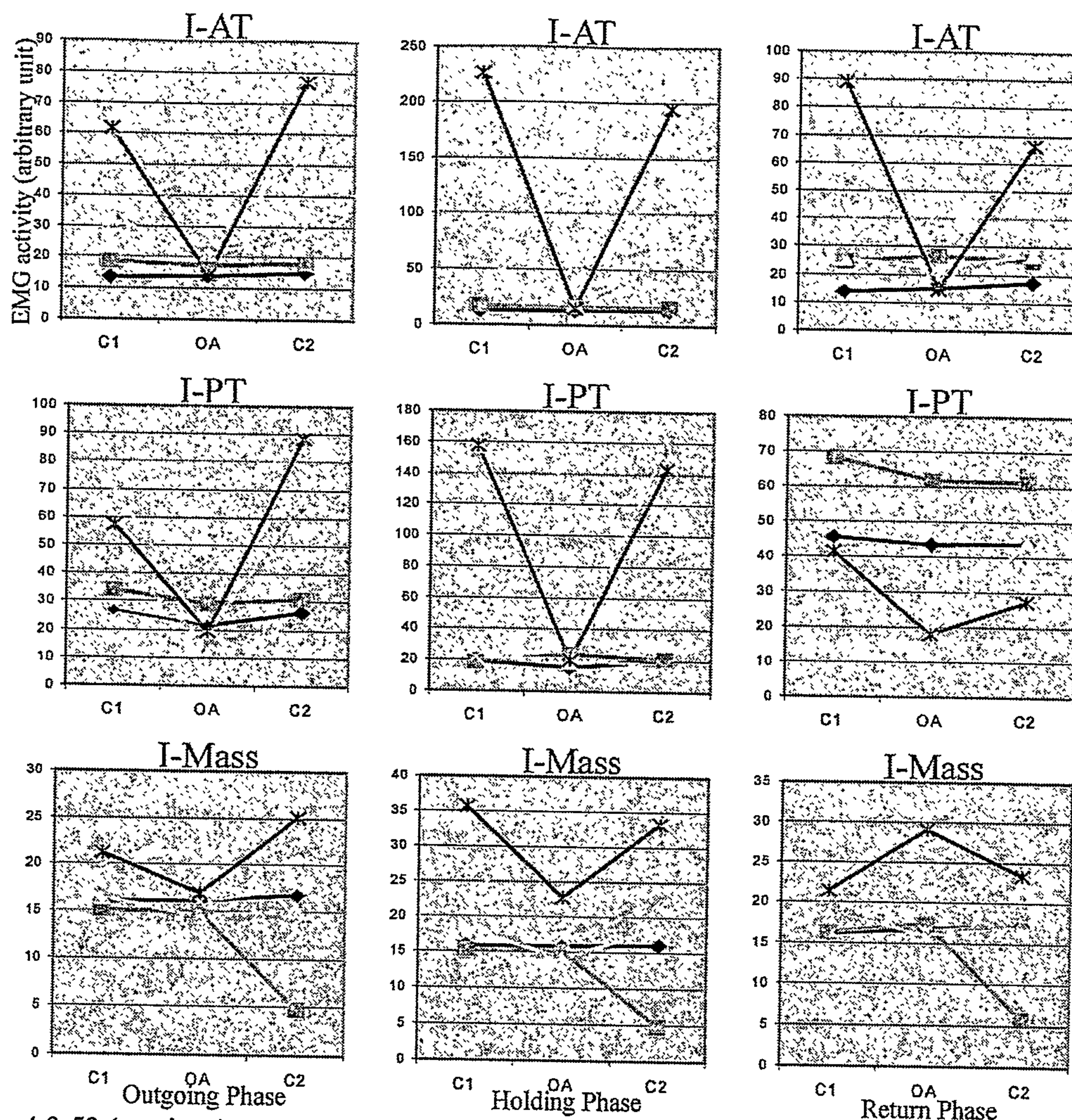


Fig. 4.3-53 (continue)

Subjects	Onset			Offset		
	Control 1	Occlusal alteration	Control 2	Control 1	Occlusal alteration	Control 2
1	0.19	0.34	0.37	0.14	0.04	0.25
2	0.41	0.31	0.24	0.24	0.18	0.33
3	0.13	-0.34	0.25	-0.34	-0.61	0.52
4	0.45	0.29	0.51	0.31	0.17	0.16
5	0.20	0.41	0.63	0.56	0.18	0.59
Mean $\pm$ SD	0.28 $\pm$ 0.14	0.20 $\pm$ 0.31	0.40 $\pm$ 0.17	0.18 $\pm$ 0.33	-0.01 $\pm$ 0.34	0.37 $\pm$ 0.18

Table 4.3-12 The mean onset and offset time difference between the MIPT movement and contralateral IHLP activity from each subject under the three occlusal conditions during fast laterotrusion at low closing force level. Positive values indicate that, in this subject, the IHLP activity started (or stopped) earlier than the MIPT displacement.

Table 4.3-12 shows that, during fast laterotrusion with low closing force, the occlusal alteration did not significantly change the onset difference between the IHLP activity and the MIPT movement. However, the offset time difference under the occlusal alteration condition was smaller than that under the control 1

and 2 conditions, with significant differences between the occlusal alteration and control 1 conditions.

(A) Outgoing phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	1	3 (1)	1	1	3 (1)	1	1	3 (1)	1
	entire	1	4 (1)		1	4 (1)		1	4 (1)	
C_AT		2	3	(1)	2	3 (1)		1	4 (1)	
C_PT			5	(1)		5 (1)			5 (1)	
C_MASS			4 (1)	1		5 (1)			5 (1)	
I_AT			2	3 (1)		2 (1)	3		2 (1)	3
I_PT			2 (1)	3		2 (1)	3		2 (1)	3
I_MASS			2	3 (1)		2 (1)	3		3 (1)	2

(B) Holding phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP										
	entire		3 (1)	2		3 (1)	2		3 (1)	2
C_AT		2	2	1 (1)	2	2 (1)	1	1	3 (1)	1
C_PT			4	1 (1)		4 (1)	1		5 (1)	
C_MASS			2 (1)	3		3 (1)	2		3 (1)	2
I_AT		1	1 (1)	3		2 (1)	3		2 (1)	3
I_PT		1	2 (1)	2	1	2 (1)	2		3 (1)	2
I_MASS			2	3 (1)		2 (1)	3		3 (1)	2

(C) Return phase

Muscles		Criterion 1			Criterion 2			Criterion 3		
		S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower	S/S higher	No S/S	S/S lower
C_IHLP	3 mm	2	2 (1)	1	2	2 (1)	1	2	2 (1)	1
	entire	1	2 (1)	2	1	3 (1)	1	1	4 (1)	
C_AT		2	3	(1)	2	3 (1)			5 (1)	
C_PT		2	2	1 (1)	1	3 (1)	1	1	3 (1)	1
C_MASS			3 (1)	2		4 (1)	1		4 (1)	1
I_AT		1	2 (1)	2		3 (1)	2		3 (1)	2
I_PT			3 (1)	2		3 (1)	2		4 (1)	1
I_MASS		1	2	2 (1)		3 (1)	2		5 (1)	

Table 4.3-13 A summary of the influence of the occlusal alteration on jaw-muscle EMG activity at the (A) outgoing, (B) holding and (C) return phases within each subject during fast laterotrusion at low closing force. The numbers indicate the number of subjects who showed a statistically significantly higher (S/S higher) activity, no significant influence (no S/S), or significantly lower (S/S lower) activity under the occlusal alteration. The number in brackets is the results of the two sham overlay subjects. The first row of C_IHLP in (A) and (C) shows the comparison between EMG activity at 3 mm away from intercuspal position at the outgoing and return phases (with normalizing method one), respectively, and the second row shows the comparison between the EMG of the entire phase. Criterion 1, 2 and 3 refer to analyzes performed under progressively more stringent criteria (see Methods). C_: contralateral; I_: ipsilateral; AT: anterior temporalis; PT: posterior temporalis; MASS: masseter.

Table 4.3-13 shows the summary of the influence of the occlusal alteration within individual subjects. As during the slow laterotrusion, the influence of the occlusal alteration on the contralateral jaw muscles during fast laterotrusion was quite variable, and that on the ipsilateral jaw muscles showed a significantly lower activity in most of the subjects, especially at the outgoing and holding phases. The small sample size could be the reason why there was no significant difference in the mean EMG comparison.

As previously mentioned, the influence of the occlusal alteration on the IHLP activity might change from a significantly higher effect at the high closing force to a significantly lower effect at the low force. However, this did not happen at the two movement speeds. The influence of the occlusal alteration on the contralateral IHLP at the fast moving speeds was similar to the slow speed with slight variation (e.g. a change from a significantly higher (or lower) effect to no significant effect or reverse).

Position	Subject	Outgoing	Holding	Return
Supero-medial	01	X	X	X
	02	X (↓)	↓	X (↑)
Infero-medial	03	X	X	X
	04	X	↓	↓

Table 4.3-14 The influence of the occlusal alteration on the contralateral IHLP activity associated with the electrode recording site in four subjects where electrode position was verified by CT scan data. Position column indicates that, in these subjects, the recording sites were located in the superior- (or infero-) medial quarter of the IHLP. In the right three columns, the influence of the occlusal alteration on the IHLP during each entire phase is shown (based on Criterion 2). The symbols in brackets indicate the results at the 3-mm MIPT displacement, if differing to the results of the entire phase. Subjects in each quarter are listed in an arbitrary order. ↑: significantly higher due to the occlusal alteration; X: no significant changes; ↓: significantly lower.

In four (of five) subjects, the electrode positions within the IHLP were verified by CT scan data. No association between the influence of the occlusal alteration

on the IHLP activity and the recording sites could be found (Table 4.3-14). The low sample size precludes any definitive comments here.

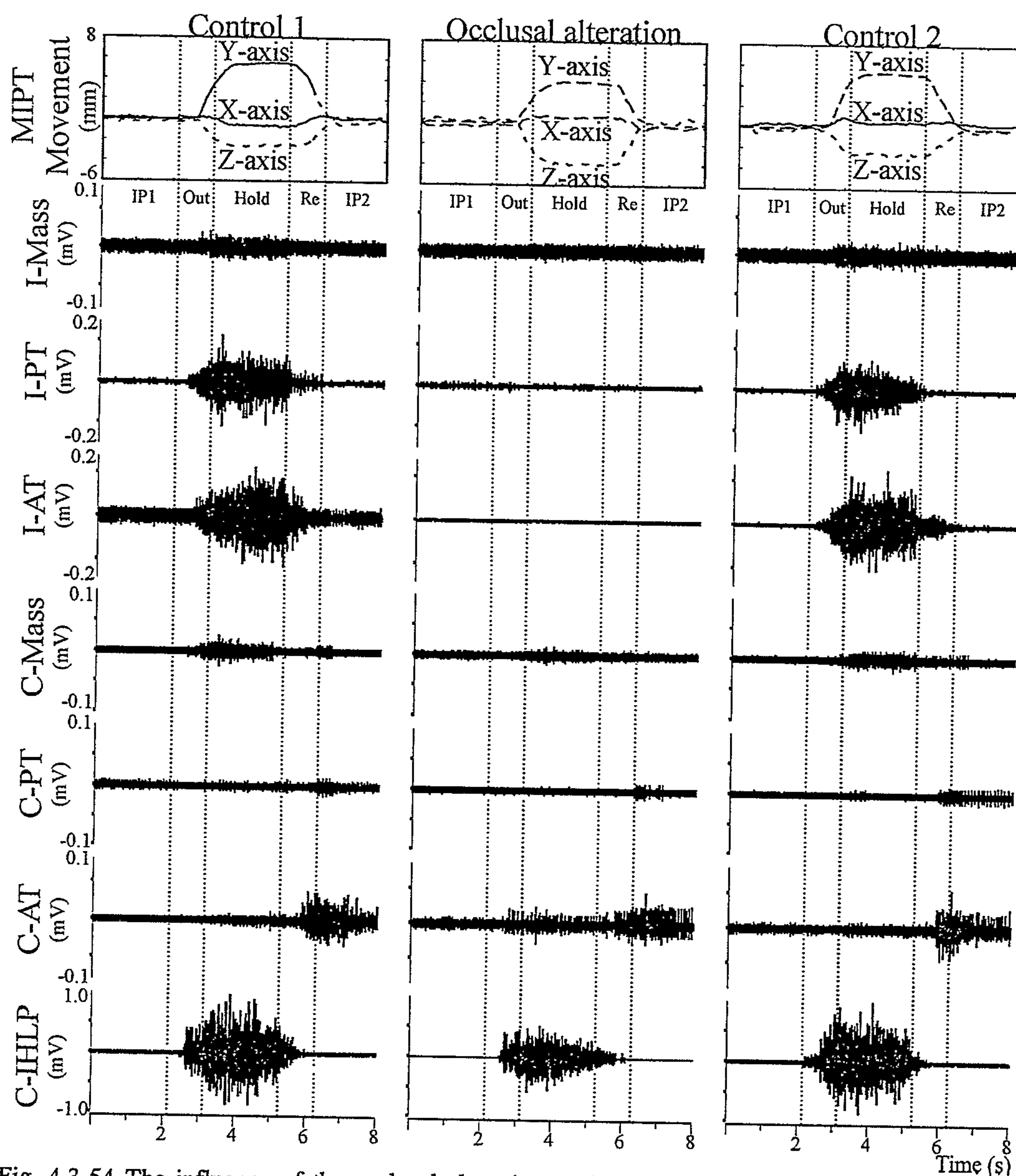


Fig. 4.3-54 The influence of the occlusal alteration on jaw muscles during fast laterotrusion at low closing force level. Examples of raw EMG activity under the control 1, occlusal alteration and control 2 conditions are displayed. Each vertical dotted line separates two phases. Each trace of muscle activity is displayed at the same amplitude under three conditions. C-: contralateral side to the occlusal alteration and the direction of laterotrusion; I-: ipsilateral side; IHLP: inferior head of lateral pterygoid; AT: anterior temporalis; PT: posterior temporalis; Mass: masseter; IP1: intercuspis position 1 phase; Out: outgoing phase; Hold: holding phase; IP2: intercuspis position 2 phase; MIPT: mid-incisor point; X-axis: antero-posterior axis; Y-axis: medio-lateral axis; Z-axis: supero-inferior axis.

The qualitative assessment showed that the occlusal alteration did not change the overall pattern of activity of the jaw muscles recorded, except for the ipsilateral anterior and posterior temporalis in two subjects. In these two subjects, the

ipsilateral anterior and posterior temporalis showed an increase at the outgoing phase, a peak at the holding phase and then a return under the control 1 and 2 conditions, but the EMG activity remained at the level of IP1 phase throughout the movement under the influence of the occlusal alteration (e.g. Fig. 4.3-54). As in the other two laterotrusion tasks, the comparison between the EMG activity at each mm of MIPT displacement during fast laterotrusion showed that the effect of the occlusal alteration did not increase or decrease gradually as the MIPT moved progressively further away from the intercuspal position. And the most predominant difference tended to be at 2 – 4 mm away from the intercuspal position (e.g. Fig. 4.3-55 at the outgoing phase).

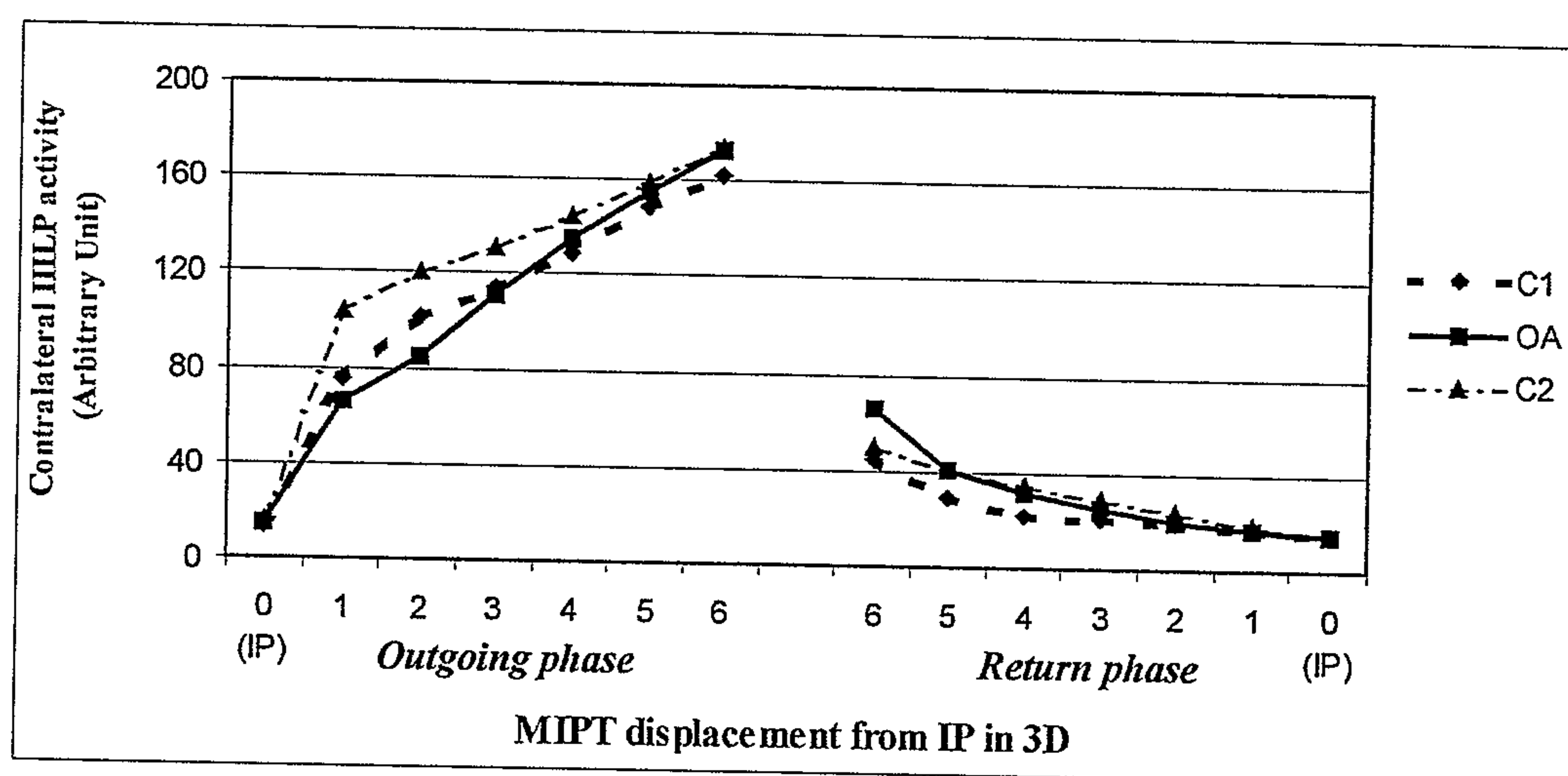


Fig. 4.3-55 Example of the influence of the occlusal alteration on the contralateral IHL activity at each mm of MIPT movement (with normalizing method one) during fast laterotrusion at low closing force. C1: control 1 condition; OA: occlusal alteration condition; C2: control 2 condition.

5 Discussion

The discussion section is divided into three major parts. The first part concerns the indirect registration of the coordinates of condylar points with a six-degrees-of-freedom jaw tracker. The second part discusses the influence of the occlusal alteration on the working-side condylar movement based on the analysis of multiple condylar points. The third section discusses the activity pattern of the jaw muscles during three laterotrusion tasks and the influence of the occlusal alteration on the activity patterns.

5.1 Registration of coordinates of anatomical condylar points in JAWS-3D system (also see Section 4.1 for results)

5.1.1 *Distributed versus unilateral fiducial marker*

The results from the perspex model and dry skull support the use of a distributed fiducial marker in reducing the error of determination of an anatomical condylar point to ~0.5 mm for most ipsilateral and contralateral points. This improved methodology with a distributed marker results in an error that is less than that seen with the use of a single unilateral fiducial marker which exhibited an error of >1.0 mm for most condylar points (Swintara *et al.*, 2001).

A limitation of this unilateral fiducial marker was that the points on the fiducial-marker box that defined the transient coordinate system were located within a small box (30 X 30 X 30 mm) while the points of interest were located some distance outside the confines of the box. Although, mathematically, two points can determine an axis, their measurement error influences the accuracy with which other points can be calculated. If a third point of interest is between the

two axis-defining points, the maximal error in the coordinates of the third point will be the same as the measurement error of the axis-defining points. If the third point is beyond the axis-defining points, the calculation error will increase as the distance increases.

There are three methods to reduce this error: (a) increase the accuracy with which the axis-defining points are measured, (b) increase the number of axis-defining points, and (c) increase the distance between the axis-defining points. The present study applies the first and the third methods. The axis-defining points, i.e. the internal reference points (SD: 0.07 mm), were more accurate than the single measurement used previously (Swintara *et al.*, 2001). The distribution of the internal reference points was also larger than that of the previous axis-defining points in the unilateral fiducial marker, and the points of interest to be calculated (i.e. condylar and LED points) were located between the internal reference points.

5.1.2 Sources of error of the indirect measurement

First is the limitation of the hardware. The resolution of the CT images is 0.67 mm in antero-posterior and medio-lateral axes and 1 mm in the supero-inferior axis, and the accuracy of the MicroScribe-3DX is ~0.23 mm. Since the error of the indirect method was ~0.5 mm along each axis, it is very likely that the majority of the error is in the imaging resolution. However, further investigation is needed on this issue, since only one set of CT scans was taken in this study. Second, due to the superimposed nature of the CT images and the CT resolution, the condylar Gutta Percha dots (~0.5 mm in diameter) tend to appear as small

squares on the CT images with ~ 1.3 mm sides. In addition, the exact location within each condylar point determined from the CT images may not be exactly the same as the location of each point as digitized by the MicroScribe-3DX in the direct measurement. Third, is the ability to precisely reposition the fiducial-marker device between the CT scanner and the MicroScribe-3DX machine which were located in separate rooms. Fourth, the MicroScribe-3DX relies on the operator placing the measuring tip accurately at the recording point, and therefore, the accuracy with which the tip is placed could become a source of error. The accuracy of placement of the MicroScribe-3DX tip is shown by the SD of repeated measurements of the fiducial marker points and LED points (about 0.15 mm).

When performing measurements on living humans, an additional source of error is any head movement that could occur during registration with the MicroScribe-3DX. This possibility of head movement can be minimized by using an additional appliance for stabilization, and by reducing the measuring time. To reduce time, separate measurements were made of the 48 fiducial marker points before the experiments and six preselected points plus three LED points during the experiments. In addition, repeating two continuous sets of measurements would allow us to check whether there was a head movement.

5.1.3 Expression of 3D movement of the condyle

The use of six parameters (the translatory movements of a selected point and the rotatory movements about three axes) can accurately register the movement of a 3D object but, without knowledge of condylar morphology of individual subjects,

one could misinterpret condylar movements. Therefore, multiple points with specific anatomical significance should be used and can provide an image of 3D condylar movement.

The positional relationship, on or within the condyle, is required between the selected point used to define the six parameters and the points of anatomical significance. As condylar movement studies usually investigate the association between the condyle and the surrounding tissues, points located at the condylar borders would be appropriate.

Mathematically, a minimum of three non-collinear points is required for reconstructing the movement of the condyle but to provide a better overall image of condylar movement, a minimum of five points is recommended: the most superior, the most anterior and the most posterior points in a selected parasagittal plane, and the medial and the lateral poles of the condylar head.

Further, with the current method, the contour of the condylar head and articular fossa and eminence could be fully reconstructed with acceptable accuracy. With the JAWS-3D recordings, a computer animation of the 3D movement of the condyle could be available as suggested by Palla and coworkers (1997).

5.2 The influence of an occlusal alteration on working-side condylar movement (also see Section 4.2 for results)

5.2.1 Outgoing phase during laterotrusion

The present study has shown that the occlusal alteration had an immediate effect on the movements of the multiple working-side condylar points during the outgoing laterotrusion. These results are consistent with the previous six-degrees-of-freedom studies (Coffey *et al.*, 1989; Hobo and Takayama, 1989; Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998), which suggested that an occlusal alteration could change the movements of a single arbitrary condylar point on the working and/or balancing side. Our results showed the paths of the multiple working-side condylar points under the occlusal alteration were significantly more inferior and anterior to those under the control conditions at the same amount of MIPT displacement from the intercuspal position. These data are also consistent with a previous study (Ogawa *et al.*, 1998) which used a single arbitrary condylar point and which showed a significant increase in the anterior and inferior components of the working-side condylar movements at the 2nd mm of mandibular displacement away from the intercuspal position. Our results also showed that the occlusal alteration caused a significant reduction in the rotation angle (in absolute values) in the frontal and horizontal planes at both MIPT displacements and a significantly larger (in absolute values) opening angle (i.e. in the sagittal plane) at the 5th mm of MIPT displacement. In addition, the differences in condylar point displacement and rotation between the control conditions and the occlusal alteration increased the further the MIPT was away from the intercuspal position.

A limitation of these previous studies is that the data were displayed in terms of a single point whose anatomical location was unclear. Another limitation is that the condylar paths, immediately after the removal of the occlusal alteration, were not investigated. Therefore, the possible involvement of other factors, such as time-dependent factors was not considered. For example, muscle fatigue may influence the mandibular and condylar movements and this could account for some of the effects observed. Generally, in the outgoing phase, the rotation angles in the frontal and horizontal planes especially, and the anterior and inferior components of the condylar movement under the occlusal alteration condition were significantly different to those under the control 1 and 2 conditions. And there was no significant difference between the control 1 and 2 conditions at all rotatory angles and all components of condylar tracings at both the 3rd and 5th mm of MIPT displacement. Thus, these data indicate that the occlusal alteration is the major factor that caused the significant changes in the working-side condylar movement and the rotatory angles, and that time-dependent factors did not play a major role.

5.2.1.1 Biomechanical explanation of the influence of an occlusal alteration on mandibular and condylar movement

Generally, during the outgoing phase of laterotrusion, the MIPT moved laterally toward the working side and inferiorly, with a slight variation in the antero-posterior direction. In this experiment, the inclination of the tooth guidance was increased by $\sim 10^\circ$ under the occlusal alteration. As indicated by Sarinnaphakorn and coworkers (1997), which had the same occlusal-alteration design as this study, the occlusal alteration resulted in a steeper inclination in the MIPT

tracings in the frontal plane. Therefore, when the MIPT was at the same distance three-dimensionally away from the intercusp position, the position of the MIPT under the occlusal alteration was more inferior and less lateral than that under the control conditions during the outgoing phase. For example, in Fig. 5.2-1, arrows "a" and "b" (solid lines) indicate the mandibular movement at the first permanent molar region under the natural tooth guidance and the overlay guidance, respectively, during the laterotrusion. The tips of the solid arrows are the same distance away from the intercusp position (IP) under both conditions. Arrows with dotted lines indicate the lateral and inferior components of the mandibular movement. Under the overlay guidance, the inferior component was greater and the lateral component was less than those under the natural tooth guidance.

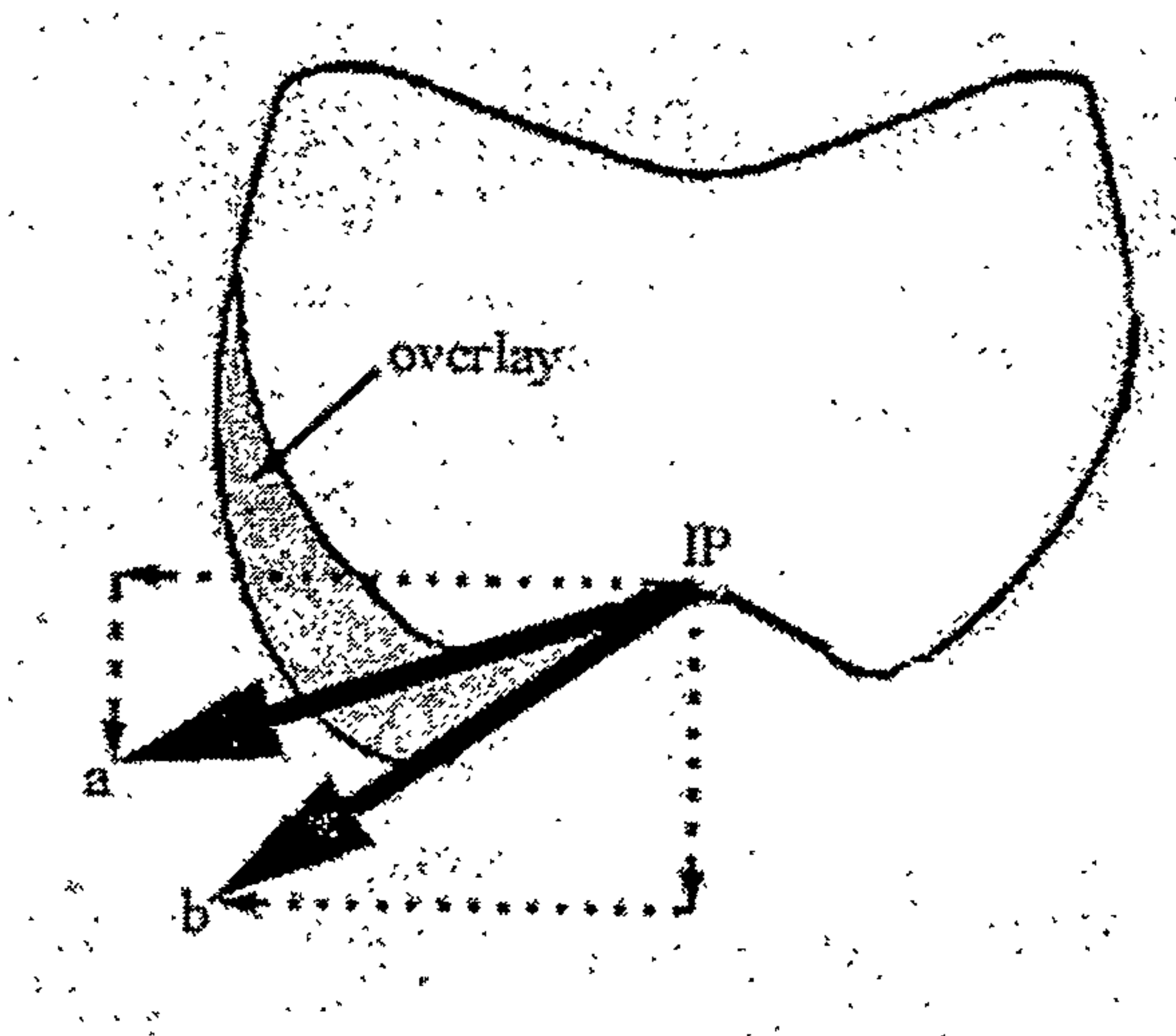


Fig. 5.2-1 The influence of the occlusal alteration on the mandibular movement in the frontal plane during laterotrusion. Arrow "a" is the mandibular movement under the natural tooth guidance. And arrow "b" is the mandibular movement under the overlay guidance. IP: intercusp position. Dotted arrows: vector components.

In the horizontal plane, the mandible rotates toward the working side during the outgoing laterotrusion. Therefore, due to the positional relationship of the MIPT to the rotation centres, the MIPT moves laterally toward the working side and the balancing-side condyle moves anteriorly and slightly medially (e.g. Fig. 5.2-2). As previously mentioned, the occlusal alteration causes a decrease in the lateral component of the mandibular movement at the molar region. It is proposed

therefore that the occlusal alteration causes a decrease in the rotation angle in the horizontal plane (about the Z-axis; i.e. supero-inferior axis) and a less anterior and medial displacement of the balancing-side condyle. This proposal was supported by our results that the rotation angles about the Z-axis were 0.16° and 0.39° less (in absolute values; $p < 0.05$) under the occlusal alteration than those under the control 1 condition at the 3rd and 5th mm, respectively, of MIPT displacement away from the intercuspal position (see Table 4.2-2). The proposal is also supported by Sarinnaphakorn and colleagues (1997) who showed a significant reduction in the anterior displacement of the balancing-side condyle at the 3rd mm of MIPT displacement during laterotrusion. Although no significant difference in the medial component of the balancing-side condylar movements was found by Sarinnaphakorn and colleagues (1997), this could be due to the smaller medial component, in comparison with the anterior component, of the balancing-side condylar movement. This smaller medial component reflects the positional relationship of the balancing-side condyle with the rotation centres during laterotrusion.

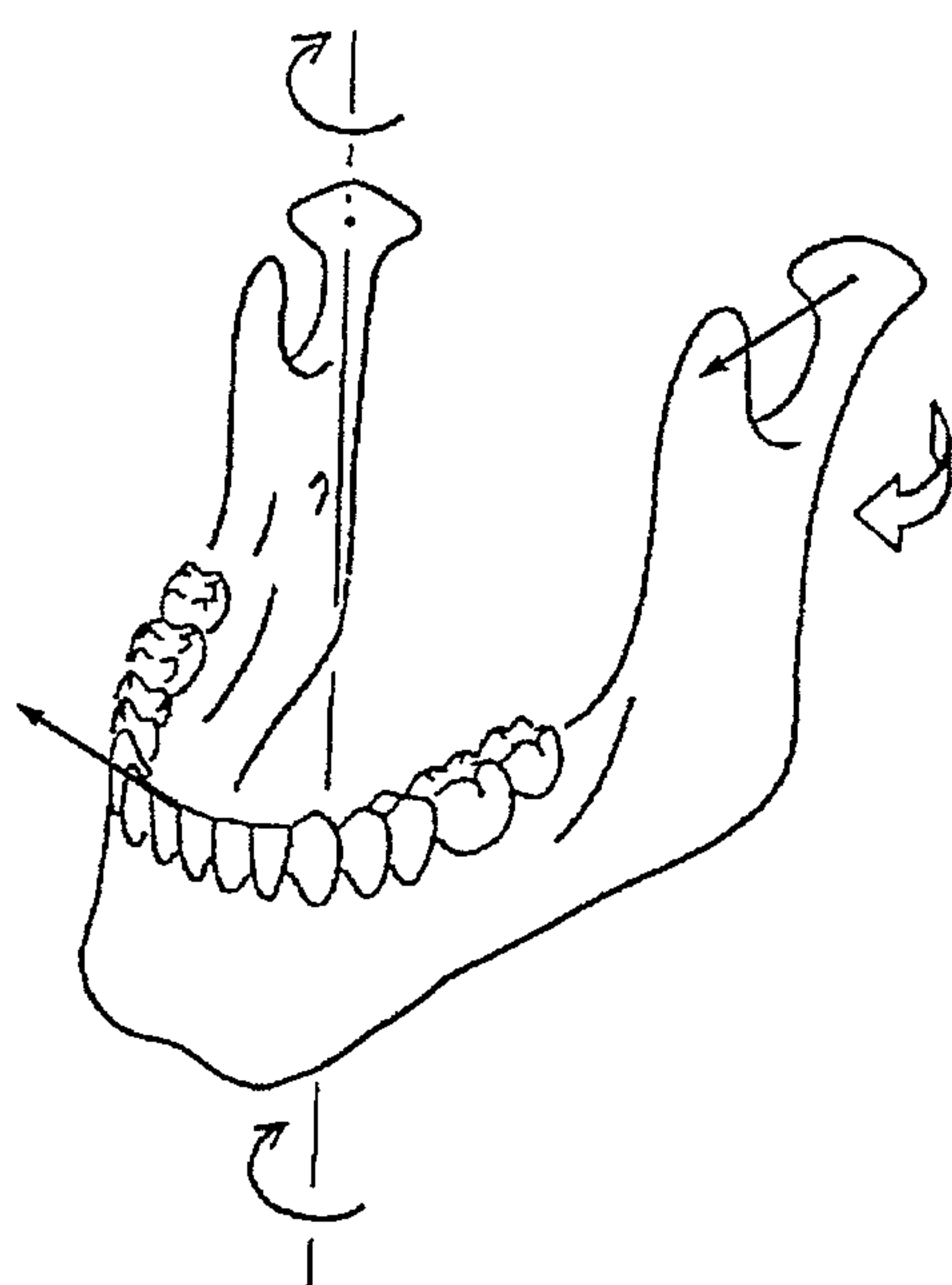


Fig. 5.2-2 Rotation about the Z-axis (i.e. supero-inferior axis, perpendicular to the horizontal plane) for a right lateral jaw movement. During laterotrusion, the MIPT moves laterally toward the working side, and the balancing-side condyle moves anteriorly and medially. This simplified view of a working-side movement does not show the translation of the mandible that may also occur (modified from Thomson, 1990).

In the horizontal plane, the mandible (including both condyles) can also shift toward the working side at the early stage of the laterotrusion (known as the immediate side shift at the condylar region) in some subjects. Therefore, the decrease in the lateral movement at the molar region under the occlusal alteration may also occur through a decrease in the lateral shift of the mandible. Thus, subjects with immediate side shift may show a decrease in the lateral component of the condylar movement under the occlusal alteration. However, previous studies (Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998) and the present study showed that, overall, the occlusal alteration did not alter the lateral component of the working-side (see Table 4.2-1) and non-working-side condylar movement during laterotrusion. One possible explanation is that in all three studies, the authors did not separate the subjects into the immediate and progressive side shift groups, and therefore, the overall comparison might not show any difference. Another possibility is the occlusal alteration does not have any effect on the lateral translatory shift of the mandible. Further studies are needed to clarify these issues.

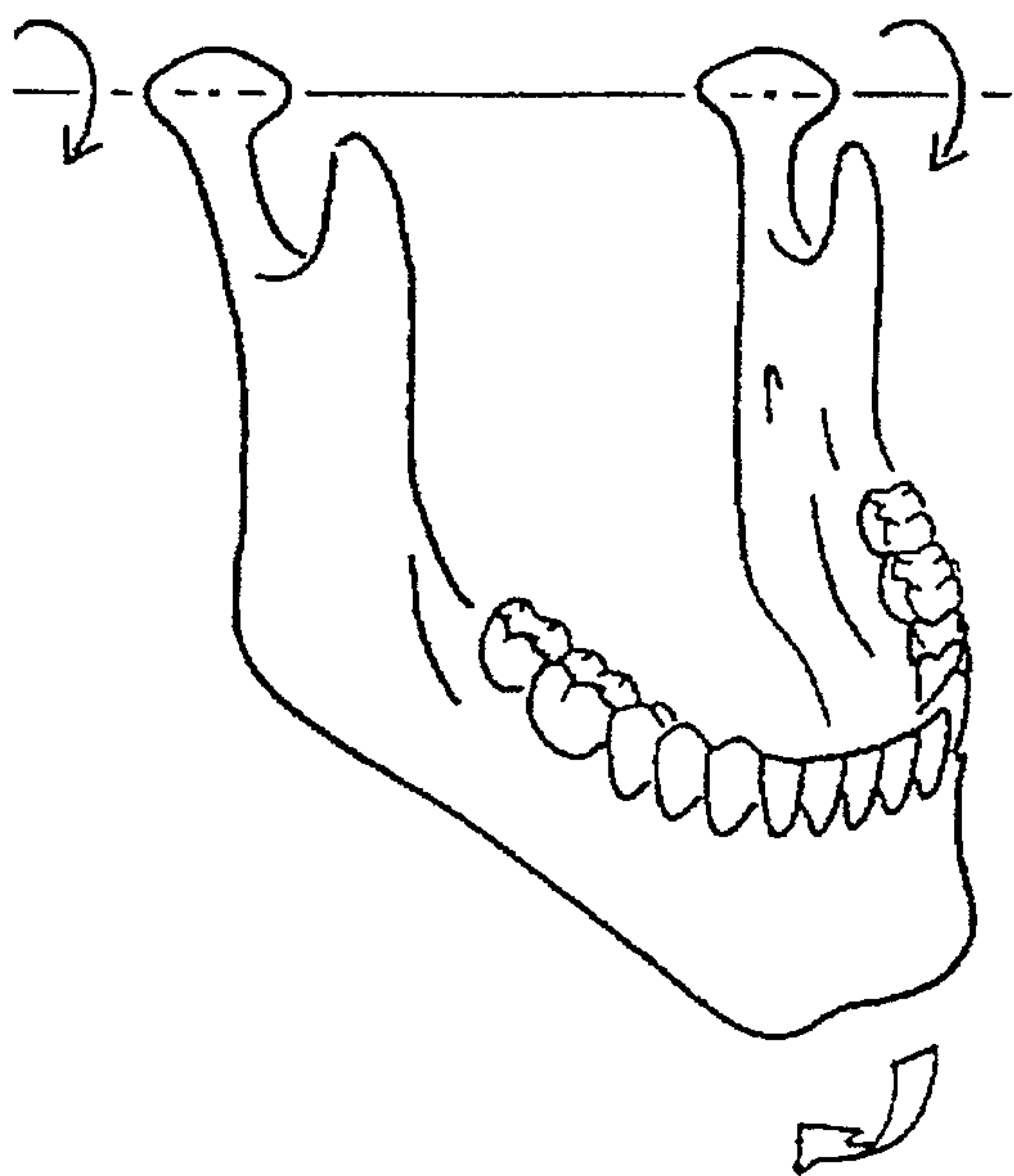


Fig. 5.2-3 An increase in the mandibular opening angle could increase the inferior movement at the level of the teeth (from Thomson, 1990).

As previously mentioned, there is a more inferior displacement at the level the teeth under the occlusal alteration in comparison with natural tooth guidance. There are three possibilities here. One relates to an increase in the angle of opening rotation in the sagittal plane when the occlusal alteration is present in comparison with natural tooth guidance (e.g. Fig. 5.2-3). The other is that the working-side mandible translates more inferiorly to that under the natural teeth (control) guidance. The third possibility is a combination of both. Our results (see Table 4.2-2) showed that the angles of opening rotation in the sagittal plane (about the Y-axis) under the occlusal alteration were 0.10° and 0.33° larger (in absolute values) than those under the control 1 condition at the 3rd and 5th mm of MIPT displacement, respectively. Significant differences were apparent at the 5th mm. These data support the first proposition. On the other hand, Ogawa and coworkers (1998) as well as this study (see Table 4.2-2) showed a significant increase in the inferior component of the working-side condyle under the occlusal alteration during laterotrusion. This latter finding suggests that both possibilities play a role.

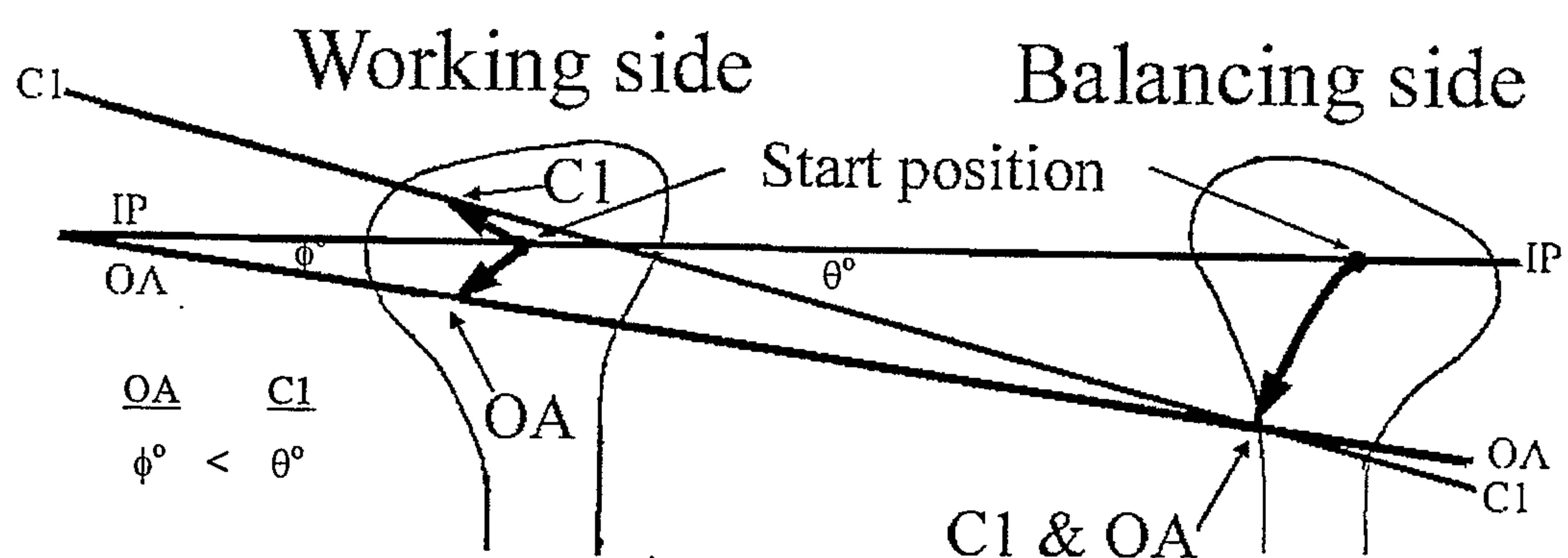


Fig. 5.2-4 Frontal view of working- and balancing-side condyles. The occlusal alteration influences the rotation angle about the X-axis (i.e. perpendicular to the frontal plane). Bold arrows indicate the condylar displacement during laterotrusion. Small arrows indicate the starting and end position of the condylar points under the control 1 condition (C1) and occlusal alteration (OA). Three solid lines link the working- and balancing-side condylar points at the start position or during the laterotrusion under the control condition or the occlusal alteration. This figure is not drawn to scale (modified from Mohl *et al.*, 1988).

In the frontal plane, previous studies (Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998) showed that an occlusal alteration did not cause any significant change in the lateral and inferior components of the balancing-side condylar movement during laterotrusion. On the other hand, Ogawa and coworkers (1998) and the present study (see Table 4.2-1) showed a significant increase in the inferior component of the working-side condylar movement but not in the lateral component. Together, these may cause a reduction in the rotation angle in the frontal plane (about the X-axis). For example, in Fig. 5.2-4, the angle formed between the inter-condylar lines (linking arbitrary working- and balancing-side condylar points) at the start position and during laterotrusion is smaller under the occlusal alteration than that under the control condition. Our results support this assumption. At the 3rd and 5th of MIPT displacement in Table 4.2-2, the rotatory angles in the frontal plane were 0.15° and 0.40° less under the occlusal alteration than those under the control 1 condition.

5.2.1.2 *The influence of selection of condylar point*

Generally, the selection of the condylar points did not influence the overall statistical results of the investigation of the effect of the occlusal alteration on the working-side condylar path. All five points showed a significant difference between the control 1 and the occlusal alteration conditions in the X-axis and the Z-axis at the 3rd and 5th mm of MIPT displacement. However, the selection of the condylar points had a significant influence on the magnitude of the difference in the displacement. As shown in Table 4.2-3, the condylar displacement differences between the control 1 and the occlusal conditions at the lateral pole

and the most anterior point were significantly different to those at the most posterior pole and the medial pole in all axes.

When a three-dimensional solid object performs a translatory movement, all the points in the object show the same amount of displacement. However, when the object performs a rotatory movement, each point in the object exhibits a different path. Therefore, the influence of the occlusal alteration on the condylar tracings was different among the five condylar points due to their positional relationships to the rotatory centres. In our results, the occlusal alteration caused an average of 0.16° reduction (in absolute values) in the horizontal plane at the 3rd mm of MIPT displacement. By assuming that the distance between the medial and lateral poles is ~15 mm, this rotation would cause a difference in condylar displacement of ~0.04 mm. This value was very close to the difference (~0.05 mm) in condylar displacement in the X-axis between the lateral and medial poles (see Table 4.2-3). Although this difference was smaller than the accuracy of the JAWS-3D (~0.1 mm for calculating the path of a single condylar point), the error made in comparing multiple condylar point displacements with one another would be considerably smaller because the systematic error in the positional determinations is eliminated. This is because the comparison of multiple condylar points used measurements made during the same trials, and the distance between the condylar points was much smaller than that between the condylar points and the referencing device (i.e. the target frame of JAWS-3D). Each calculated condylar point displacement is therefore subject to the same systematic error and so the error will cancel when comparing the difference in displacement between these points.

Although the quantitative difference between condylar displacement under the control 1 and occlusal alteration conditions varied between each condylar point, the results of the overall statistical comparison were not influenced by the selection of the condylar points. This might be due to the fact that the occlusal alteration caused a difference in the translatory movements of the working-side condyle, and this difference might have a P value much smaller than 0.05. Therefore, the slight variation in the amount of the displacement, due to condylar point selection, did not appear to influence the final results of the statistical comparison.

5.2.1.3 Clinical implications and significance

The clinical relevance of this study as well as other six-degrees-of-freedom studies (Coffey *et al.*, 1989; Hobo and Takayama, 1989; Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998) was that it has provided clear evidence that an occlusal alteration changes condylar movements during laterotrusion. The quantitative changes and their clinical significance require further study in relation to the function of the temporomandibular joints. Controversy continues regarding the relationship between the occlusion and temporomandibular disorders (TMD), with data for and against a role (for reviews, see De Boever *et al.*, 2000a, b). Whether there is a relationship between an occlusal alteration and TMD was not the purpose of the present study, and the results of the present study have no bearing on the issue. However, this study as well as previous studies (Coffey *et al.*, 1989; Hobo and Takayama, 1989; Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998) showed clear evidence that a change in the occlusion could significantly

influence the condylar movements during laterotrusion. Whether such changes play a role in TMD is an avenue for further investigation.

Further, the occlusion is only one possible factor that "might" play a contributory role in temporomandibular disorders. For example, Coffey and colleagues (1989) changed the occlusion between lateroprotrusive (mesial) and lateroretrusive (distal) canine guidance. The results showed that, within the same subject, the lateroretrusive canine guidance was associated with a more posterior working-side condylar path. However, Yang and coworkers (2000) investigated the condylar path of two groups of subjects, one with mesial and the other with distal canine guidance. The results showed that there was no difference in the laterotrusive inclinations and working-side condylar movements between these two groups. Thus, according to Coffey and coworkers (1989), when other factors remain unchanged, the introduction of lateroretrusive canine guidance could cause a more posterior working-side condylar path. Whereas, according to the results of Yang and coworkers (2000), people with natural distal canine guidance may not necessarily show a more posterior path than those with natural mesial canine guidance, since other factors (such as the shape of the jaws, muscle fibre angulations, origins and insertions, and so on) may also play a role.

In many early prosthodontic studies (e.g. Page, 1955; Clayton *et al.*, 1971; Schulte *et al.*, 1985; Dupas *et al.*, 1987), it was suggested that condylar guidance could not be changed, unless a pathological problem was present. As a result, it is widely accepted that the occlusal guidance of prosthetic restorations should be in harmony with condylar guidance. Based on this theory, some clinical

procedures were proposed to register condylar guidance so that restorations could be constructed in harmony with condylar guidance. Although condylar guidance might not be changeable in a short-term, an important question is whether these clinical procedures register the condylar guidance or the condylar movements. As defined in The Glossary of Prosthodontics Terms - Seven Edition (1999), condylar guidance is "*the mandibular guidance generated by the condyle and articular disc traversing the contour of the glenoid fossae*" and condylar path (or movement) is "*the path traveled by the mandibular condyle in the TMJ during various mandibular movements*". Some fully adjustable articulators use pantographs to record condylar tracings for restoration purposes. However, according to the definitions above, pantographs are purported to register condylar movements, and recent studies (Coffey *et al.*, 1989; Hobo and Takayama, 1989; Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998), as well as the present study suggest that a change in the occlusion could lead to an alteration in condylar movements.

It is necessary to further investigate whether there is need to modify clinical procedures that purport to register condylar guidance. For example, it might be more accurate to use an inclined central bearing plate, rather than the common use of a flat central bearing plate during pantographic recordings for prosthodontic reconstruction. This proposal acknowledges that most lateral guidance of natural dentition is inclined and not flat, and our data indicate that a change in tooth inclination can have a significant effect on condylar movements.

5.2.2 Return phase during laterotrusion

Our results have shown that an occlusal alteration had an immediate effect on the working-side condylar movement at the return phase of laterotrusion. The effect of the occlusal alteration at the return phase was qualitatively similar to that at the outgoing phase, although the working-side condylar paths at the return phase were different to those at the outgoing phase. The results showed that the paths of the multiple working-side condylar points under the occlusal alteration were significantly more inferior and anterior to those under the control conditions at the same amount of the MIPT displacement from the intercuspal position. These results are consistent with the studies at the outgoing phase by Ogawa and colleagues (1998) that used a single arbitrary condylar point, and our study at the outgoing phase that used multiple condylar points. During the outgoing phase, both the present study and the study by Ogawa and colleagues (1998) showed a significant increase in the anterior and inferior components of the working-side condylar movements under the occlusal alteration.

In addition, our results showed that the occlusal alteration could significantly change the rotation angles of the mandible during the return phase of laterotrusion in all three planes, except that the occlusal alteration did not cause a significant change in the rotation angle in the sagittal plane at the 3rd mm of MIPT displacement. The difference between the control conditions and the occlusal alteration condition decreased, the closer the MIPT approached the intercuspal position. These data are consistent with our results at the outgoing phase.

5.2.2.1 The influence of the selection of condylar points

During the outgoing phase, the selection of the condylar points did not change the overall statistical results of the comparison between the control 1 and occlusal alteration conditions. The occlusal alteration caused a significantly more anterior and inferior path in all condylar points at the 3rd mm and 5th mm of MIPT displacement. However, during the return phase, the selection of the condylar points changed the overall statistical results of the comparison between the control 1 and occlusal alteration conditions. As shown in Table 4.2-5 (a), only the lateral pole and the most anterior point showed a statistically significant change in the inferior component (Z-axis) due to the occlusal alteration, whereas the most superior and the posterior points and the medial pole did not show a statistically significant difference at the 3rd mm of MIPT displacement.

A possible explanation is that the occlusal alteration did in fact cause a difference in the inferior component of the translatory movements of the working-side condyle. With a larger sample size the difference identified in this study may have become significant. Whereas, at the 5th mm (Table 4.2-4 (b)), because the effect of the occlusal alteration on condylar paths was greater than that at the 3rd mm, the difference between the inferior displacements under the control 1 and occlusal alteration conditions had a P value much smaller than 0.05. Thus, all points showed a significant difference between the control 1 and the occlusal alteration conditions.

5.2.2.2 The involvement of other factors

During the return phase at the 3rd mm away from the intercuspal position, the inferior component of the condylar displacement under the control 2 condition not only had returned to the original level under the control 1 condition, but also the condylar path was significantly more superior to that under the control 1 condition. Since the control 2 condition was recorded immediately after the removal of the occlusal alteration, it indicated a possible prolonged effect of the occlusal alteration and that there might be other factors involved in influencing condylar movements. In other words, other than the condylar guidance and the occlusal guidance, the jaw muscles might be playing an additional contributory role in determining the pathway carried out by the condyle during condylar movements in the return phase. According to our preliminary analysis of the simultaneously recorded jaw muscle activity (see Section 4.3.2.3), the muscle activity under the control 2 condition also did not return to the level under the control 1 condition. Thus, these data suggest that there might be an association between the working-side condylar path and the muscle activity at the return phase. However, it is important to notice that this study was not designed to investigate the influence of a muscle-activity alteration on the working-side condylar path. Further studies would be needed before making any conclusions on this issue.

5.2.2.3 The contribution of mandibular deformation

The basic assumption of six-degrees-of-freedom jaw-tracking devices is that the mandibular bone is a rigid beam. Therefore, irrespective of whether the condylar referencing points were determined anatomically or mathematically, these points

were assumed to have a fixed positional relationship with the recording device. Then, the condylar movements could be calculated. As mentioned in the Introduction, when the masticatory muscles function, the generated force can lead to deformation of the mandible in a complex manner. Human clinical studies have demonstrated changes in lower posterior dental arch width during function (Goodkind and Heringlake, 1972; Omar and Wise, 1981; Grant, 1986). Finite element analysis (Korioth and Hannam, 1994) suggests that the human jaw deforms elastically in a complex manner during symmetrical and asymmetrical clenching tasks. This deformation phenomenon may cause some problems in the condylar motion studies, because the basic assumption of a rigid mandible will not be valid, especially at high force levels. However, in the assessment of condylar movement in this study, the subjects were instructed to perform the lateral movement with lowest closing force required to maintain tooth contact. Therefore, the influence of the occlusal deformation on the accuracy of our condylar movement data should be minimal.

5.2.3 Conclusion (The influence of an occlusal alteration on working-side condylar movements)

This study has suggested that a change in the occlusion could alter the rotatory angles and the movements of the working-side condyle during the outgoing and the return phases. The data indicate that changes to the occlusion can change temporomandibular joint function. Further, in prosthodontic procedures involving the recording of condylar guidance, our data suggest therefore that the recordings made are of condylar movement under the influence of the posterior determinants (including condylar guidance, the jaw muscles, etc.) and the anterior determinants (i.e. teeth). Further studies are also needed to assess any possible long-term effects of an occlusal alteration on TMJ function.

5.3 Jaw muscle activity and the influence of an occlusal alteration during laterotrusion

5.3.1 *Dynamic EMG activity of jaw muscles during laterotrusion* (also see Section 4.3.1 for results)

Most previous investigations of jaw muscle activity during laterotrusion studied whether the jaw muscles were active or not and the relative levels of activity when the jaw was positioned statically at the lateral position in comparison with intercuspal clenching. The present study investigated the dynamic EMG activity of the jaw muscles during laterotrusion in relation to the EMG activity at the intercuspal position. We used visual feedback to standardize the timing, the speed and the amplitude of the jaw movements, so we could reduce individual differences in performance of the laterotrusion tasks, and so that we could normalize the multi-unit EMG activity based on the timing of each phase. We also described a technique to further normalize the EMG activity of the IHLP based on the amplitude of MIPT movements from the intercuspal position. This allowed us to compare quantitatively the EMG activity during various phases of laterotrusion or at a specific amount of jaw displacement.

5.3.1.1 *Laterotrusion at low closing force level with slow speed*

Contralateral IHLP

Among the nine muscles recorded, the contralateral IHLP was the only muscle to show a clear increase in EMG activity throughout the outgoing, holding and return phases of laterotrusion in all subjects. These results are consistent with the findings by Gibbs and colleagues (1984), Murray and colleagues (1999) and Phanachet and Murray (2000) that showed a progressive increase during the

outgoing phase and a progressive decrease during the return phase during the laterotrusion in the contralateral IHLP. However, a recent single-motor-unit study (Phanachet *et al.*, 2002) showed no single motor unit firing during the return phase. One explanation is the different experimental designs between the two studies. The lateral movements in the present study were performed with the teeth in contact, whereas the lateral movements in the Phanachet and coworkers (2002) study were recorded with the teeth apart. With the teeth together, closing forces from active jaw-closing muscles may necessitate IHLP activity to control the rate of return of the condyle into the glenoid fossa. With the teeth apart, this controlling influence from IHLP does not appear to be required.

After being normalized, based on the amplitude of the MIPT displacement in the present study, the EMG activity of the IHLP showed two types of activity patterns during the outgoing phase. Six (of 10) subjects showed a progressive increase throughout the entire outgoing phase, whereas the other four showed a rapid increase at the first 3 mm of MIPT displacement and then reached a plateau. These results may be consistent with the previous single-motor-unit study (Phanachet, 2002) that a majority of IHLP units showed a significant increase in firing rates as the amount of jaw displacement increased in contralateral movement, and a small proportion of units did not exhibit significant differences in firing rates at different levels of displacements. Although the present study is a multi-unit EMG study, the EMG of the contralateral IHLP was recorded from a small area inside the muscles, because the tips of the intra-muscular electrodes were exposed for 2 mm only. In addition, both electrodes were carried by the same needle and placed into the muscles at the same insertion, therefore, the tips

of the electrodes were very close to each other. Since the EMG activity was recorded from a small area, it is possible that, in this region of the inferior head, the muscle fibres around the tips of the electrodes were mainly those that significantly increased their firing rates with jaw displacement (in those subjects with progressive increase in the IHLP activity). Alternatively, for those recordings of single motor units that reached a plateau, it is possible that the units had already reached the maximal amount of activity for shortening at the early stage of this particular task performed. Further additional active contraction of fibres of the IHLP may have depended on the contraction of muscle fibres located distant from the recording site.

This explanation is consistent with the recent proposal of functional heterogeneity within IHLP which could provide a possible explanation for the differences between subjects (Murray *et al.*, 1999c; Phanachet *et al.*, 2001, 2002). Functional heterogeneity suggests the possibility of differential activation within the inferior head depending on task performed. Despite the above findings of different activity patterns in different parts of IHLP, our results showed there was weak or no evidence for an association between the locations of the electrodes within the IHLP and the patterns of the IHLP activity recorded. It is possible that some features of IHLP activity may not be closely correlated with location. Indeed, Phanachet and colleagues (2002) showed that for a contralateral step task, the proportion of the units with a significant increase in firing rates due to increased jaw displacements was similar (~75%) in the supero-medial, the supero-lateral, and the infero-medial quarters. However, the Phanachet and colleagues (2002) study and the present study have a similar problem of small

sample size. Therefore, further investigations are needed to clarify whether these different patterns might be localized to a particular region within IHLP.

Contralateral anterior and posterior temporalis muscles

During the outgoing laterotrusion, the contralateral anterior and posterior temporalis muscles showed a decrease in activity from the original activity level at the intercuspal position. Then the activity in these muscles reached a plateau level of activity throughout the remainder of the outgoing phase and the holding phase. During the middle or late third of the return phase, the EMG activity returned to a level that was higher than the original level at the intercuspal position. These results are generally consistent with the proposal that the contralateral temporalis is minimally active and usually not recruited during lateral movement (Miller, 1991). Further, the results are similar to the findings by Murray and colleagues (1999) and Phanachet and Murray (2000) in that there were low correlation coefficients between EMG activity and the amplitude of condylar movement in both muscles. However, in both these earlier studies, the correlation coefficients between the EMG activity and condylar movement were calculated throughout the entire outgoing or return phases. The calculation included the rapidly changing periods, in which EMG activity might be correlated with the magnitude of the movements, and there might not be any correlation in the plateau periods. This could be a reason why low coefficients were shown in these studies. Therefore, there might be a need to investigate further the correlation between the EMG activity of the contralateral temporalis muscles and the MIPT or condylar movements during the early outgoing phase and the late return phase to study whether these muscles might be involved in

some aspect of the control of these movements during the rapidly changing periods.

Ipsilateral anterior and posterior temporalis and bilateral masseter muscles

In the ipsilateral anterior and posterior temporalis muscles and bilateral masseter muscles, more than one type of EMG activity pattern was apparent. Murray and colleagues (1999) and Phanachet and Murray (2000) also showed a variation in the EMG activity patterns in the contralateral masseter; the ipsilateral muscles were, however, not investigated in these two studies. The variation in activity patterns between subjects could be due to the unstandardized force levels or individual anatomical differences among subjects in the earlier and the present studies. The importance of force level in playing a role in determining EMG activity pattern is underscored by the results of the present study which showed that the EMG activity patterns in the ipsilateral anterior temporalis and bilateral masseter muscles could be changed with differences in closing force levels.

Bilateral submandibular muscles

During the laterotrusion, the EMG activity of the bilateral submandibular muscles remained at the same level as at the intercuspal position. These results were, however, inconsistent with previous studies. Murray and colleagues (1999) and Phanachet and Murray (2000) reported that the contralateral digastric (submandibular) muscle showed an increase at the outgoing phase, and a decrease at the return phase. The possible explanation is that in these two previous studies the laterotrusion was achieved at the maximal comfortable range of the subjects. Whereas, in the present study, the subjects were instructed to

move the lower jaw to a position near the edge-to-edge position. The larger displacement may have afforded a larger opportunity for a significant correlation to be recorded.

5.3.1.2 The influence of closing force levels

Contralateral IHLP

At the high closing force level, our results showed a significant increase in the EMG activity of the contralateral IHLP during the outgoing and return phases in comparison with that at the low closing force level. These results are consistent with Gibbs and coworkers (1984) who showed a higher IHLP activity during loaded contralateral movement than that during unloaded contralateral movement. With an inclined surface, as provided by the natural tooth guidance, the higher closing force level would generate a larger resistance to movement of the jaw from the intercuspal position. To overcome this larger resistance, a larger horizontal force would be required during the outgoing phase. Similarly, in the speed-standardized return phase, a higher horizontal force would be required to control the rate at which the lower jaw returned to the intercuspal position. The contralateral IHLP would be the main muscle providing these horizontal forces given the orientation of the muscle fibres. Uchida and colleagues (2001, 2002) suggested that the IHLP is the primary muscle involved in the generation and control of horizontal forces while other jaw muscles (masseter, temporalis and submandibular) may play a part in helping to stabilize the jaw during the isometric tasks.

When the amount of MIPT movement was taken into account, seven subjects showed a rapid increase in the contralateral IHLP EMG activity around the first 3 mm of MIPT movement, and then the activity level reached a plateau during the remainder of the lateral movement at the outgoing phase at the high closing force level. In three of these seven subjects, the EMG activity changed from a progressive increase at the low closing force level to a rapid increase and plateau at the high closing force level. As previously discussed, because the intramuscular electrodes recorded signals from a small region, it is possible that the muscle fibers around the electrodes reached their maximum efforts of output at the early stage of movement. For further shortening or increases in force from the contralateral IHLP, muscle fibres in other regions of IHLP may have been recruited. The increase in the horizontal force output required possibly led to the muscle fibres reaching their maximal output at the early stages of movement. As in the low-closing-force task, there were no associations found between the EMG patterns recorded and the locations of the electrodes within the IHLP during the high closing force task.

Some recent studies have suggested different activity patterns of single motor units within the contralateral IHLP during isometric and isotonic tasks. Uchida and colleagues (2001) reported three patterns of single-motor-unit activity following analysis of firing rates of 21 units within IHLP during isometric tasks at different force levels. The patterns were phasic, tonic and intermediate. Phanachet and colleagues (2002) reported two activity patterns for single motor units firing in association with jaw displacements during isotonic tasks. The patterns were units that showed a significant increase in firing rates as the

amount of jaw displacement increased in contralateral movement (the majority of units), and units that did not exhibit significant differences in firing rates at different levels of displacements. The present study also identified two patterns of activity during the tasks. For example, our multi-unit EMG data at the low closing force showed two patterns in the IHLP activity, namely, a progressive increase in activity and a rapid increase followed by a plateau. Such patterns might correlate with the units showing significant changes in activity and those that did not, as described in the previous study (Phanachet *et al.*, 2002). Further, the IHLP activity in three subjects changed from a progressive increase during the low-force-level task to a rapid increase at the high-force-level task. Whether this latter change in activity pattern is associated with the intermediate units, which exhibited different activity patterns at different force levels (Uchida *et al.*, 2001), is unclear and is a subject for further investigation.

Other muscles

At the high closing force, the results showed a significantly higher activities in the bilateral anterior temporalis and masseter muscles than those under the low closing force during the outgoing, holding and return phases. This indicates that these muscles are also making a contribution to the generation of the increased forces in the task at the high closing force. These results are consistent with Gibbs and coworkers (1984) who showed a higher activity in bilateral anterior and masseter muscles during loaded lateral movement in comparison with that during unloaded lateral movement.

The contralateral posterior temporalis is the only muscle that showed a lower activity during the outgoing and holding phases at the high closing force than that under the low force, although no statistically significant difference was found. Their largely horizontal fibres might suggest a posteriorly directed force to counteract the contralateral IHLP, and less force would be needed from this muscle during the outgoing phase of the lateral jaw movement at the higher closing force. It should be noted also that the posterior temporalis fibres run forward to bend sharply downward around the root of the zygomatic process. Therefore, only their direction below the zygomatic process is significant (DuBrul, 1988) and only a vector component of the total force would be in the horizontal direction.

5.3.1.3 The influence of speed of laterotrusion

At the outgoing phase, the activity of the contralateral IHLP at the fast speed was significantly higher than that at the slow speed. This suggests that the IHLP plays an important role in controlling the speed of lateral jaw movement and is consistent with the speed-dependent properties of IHLP single motor units (Phanachet *et al.*, 2001). A more rapid speed of movement would be associated with the need for a faster rate of force generation and a greater EMG output would be anticipated. At the return phase, IHLP activity was lower at the fast speed than the slow speed. This would be anticipated to allow the condyle to return more quickly to the glenoid fossa.

The onset of the contralateral IHLP was earlier than the onset of jaw movement at both speeds. The data support the notion that the contralateral IHLP plays an

important role in the initiation of the movement. Further, the onset difference at the slow speed was significantly larger than that at the fast speed. However, this might simply be a reflection of the experimental design. At the beginning of each trial, the first LED of the visual feedback was switched on for 2 s to indicate the intercuspal position phase, it was switched off for 0.6 s at the slow speed and 0.15 s at the fast speed, and then it was switched on again. Subjects were instructed to start the movement when the first LED was on again. In other words, when the first LED was switched off at the second second, subjects may have anticipated the movements. And 0.6 s (or 0.15 s) later when the first LED was switched on again in the slow (or fast) task, subjects started the movement. Therefore, there was a shorter period of time for the anticipation of the movement in the fast task in comparison with the slow task. As shown in the average EMG activity throughout the movements, the EMG activity started to change before the time at which the subjects were instructed to start the movements. The difference between the onset difference at both speeds could therefore be related these aspects of the experimental design. Further studies are needed on this issue by standardizing the timing at the beginning of a trial.

During the return phase at the slow speed, the activity of the contralateral IHLP decreased gradually. Although the EMG amplitude was much smaller than that of the outgoing phase, it did not fully return to the EMG level at the intercuspal position until the late return phase. This suggests that the contralateral IHLP is providing a small force to control the rate of return of the condylar head during the slow controlled movement task and is consistent with Wilkinson's proposal (1988). This hypothesis is indeed supported by the observation that the activity

of the contralateral IHLP at the fast speed laterotrusion task was statistically smaller than that of the slow task at the early return phase. This would be expected to allow the condyle to return rapidly to the glenoid fossa. Thus, a faster rate of return should be associated with a lower level of IHLP EMG activity that would provide less resistance to the return of the condyle to the glenoid fossa, although still providing some control on the rate.

In addition, the offset difference between the IHLP activity and MIPT displacement at the fast task was smaller than that at the slow task. However, such a difference did not suggest that the force, to control the rate of return of the condylar head as mentioned above, ceased later at the fast speed than that at slow speed. We believed that such a difference in offset time between two speeds was related to the speed of the movement. Further assessments are needed on this issue.

5.3.1.4 Normalizing methods

In the current study, visual feedback was used to standardize the timing, speed and amplitude of the movements. Therefore, visual feedback allowed us to normalize the EMG activity based on the timing of the movement for further quantitative comparison between different movement tasks or between different occlusal conditions in the later part of this study. However, because of the nature of voluntary movements, there was a slight variation between the trials of the same movement task in the same subject. Therefore, a further normalizing method would be needed to reduce the variation. In this study, a new normalizing technique, based on the amount of the MIPT movement, was introduced. There

were two approaches for this normalizing technique. One approach examined the EMG activity during an entire millimetre of displacement and the other approach used 100 EMG samples when the MIPT reached the selected amount of displacement. The results showed that the overall outcomes of the two approaches were very close. However, due to the variable nature of EMG activity, the data distribution of the second normalizing approach (i.e. 100 EMG activity samples) was slightly more variable than that of the first method (i.e. EMG activity between each millimetre of MIPT movement). Therefore, the first approach is recommended for further studies.

5.3.1.5 Limitations of the current study

The major limitation of the present EMG study was the use of surface electrodes in recording the EMG activity of the masseter and temporalis muscles. Therefore, only part of these muscles, that is, the superficial layers, provided the major contribution to the sampled EMG activity. However, the masseter and the temporalis have a complex internal architecture (Hannam and McMillan, 1994) and some parts of the muscles, for example, the deep masseter that does provide an anterior force vector component, were not recorded. In other words, the described EMG activity of these muscles only represents the superficial region of the muscles. Further studies, with several intra-muscular electrodes in various regions within the jaw muscles, are needed to provide detailed information of the role of these muscles in the lateral jaw movements.

Another limitation of this study was the uncontrolled force level. During the lateral movement tasks, subjects were instructed to use the lowest closing force

level to maintain tooth contact or to use a higher closing force at a comfortable level. Although we are confident that clearly different closing forces were being generated at the two force levels in each subject, the magnitude of the force was uncontrolled. There would be variations in defining the force levels between different subjects. Furthermore, there could be some variations in force control during different trials of the same movement in the same subject. However, currently, there is a lack of proper instruments or methods to control non-invasively the force level for this study without altering vertical dimension.

Among the previous studies, the most common approaches to the control of force levels have been the use of visual feedback from a force transducer or from the simultaneous display of the EMG level. However, the force transducers available at the moment, require an increase of the vertical dimension between the upper and lower jaws. Changes in vertical dimension alone could significantly affect EMG activity. Manns and colleagues (1981) showed a gradual decrease of EMG activity in anterior and posterior temporalis and masseter muscles with progressively increased vertical dimension from the occlusal vertical dimension. After a certain interocclusal distance, the activity in these muscles gradually increased until maximum jaw opening. In other words, a change in vertical dimension will influence the EMG activity. However, in the present study, the EMG activity was studied during lateral jaw movements under natural tooth guidance. Another issue is that the force transducers available at the present time operate under isometric conditions, whereas in this study, the EMG activity was recorded under isotonic conditions.

Another method of controlling force is to use visual feedback to control the EMG activity level at a selected percentage of EMG activity at the maximal voluntary contraction (e.g. Baba *et al.*, 2000). However, our data as well as previous studies (Gibbs *et al.*, 1984; Murray *et al.*, 1999; Phanachet and Murray, 2000) showed that the EMG activity of jaw muscles changes dynamically throughout the lateral movements. In addition, this dynamic change in the EMG activity of the jaw-closing muscles was not highly correlated with the magnitude of jaw movement (Murray *et al.*, 1999; Phanachet and Murray, 2000) nor was it uniform among jaw muscles (Gibbs *et al.*, 1984; Murray *et al.*, 1999; Phanachet and Murray, 2000). Since there was no muscle involved in the control of jaw closing force that remained at a consistent level throughout the lateral movement, the use of visual feedback of the EMG activity of the jaw muscles would not be a reliable method to control the force level during dynamic movements.

The third limitation relates to possible mandibular deformation, especially at high closing force levels. When the masticatory muscles function, the generated force can lead to deformation of mandible. Since this study investigated the relationship between EMG activity and mandibular movements, the error in mandibular movement recordings may have an influence on the results. However, we believe this influence should be minimal in this study. Previous studies suggested that during function (Hylander, 1988; Goodkind and Heringlake, 1972; Omar and Wise, 1981; Grant, 1986) or clenching (Korioth and Hannam, 1994), the human jaw deforms elastically in a complex manner. The deformations include changes in lower posterior dental arch, rotational distortion of the mandibular corpora around their axes, and parasagittal and transverse

deformation of the mandible. All these possible deformations result in an inconsistent positional relationship between mandibular points during function. The inconsistent positional relationship would lead to an error in recording the actual mandibular or condylar movements. Jiang (1992) showed that during unilateral clenching, the mandible had a bending deformation and the arch width decreased. This led Jiang (1992) to suggest that the actual condylar displacement was more medial and superior than that measured by the Pantograph used in Jiang's study.

In the present study, the lower clutch of the JAWS-3D was attached to the ipsilateral incisors and canine, and the reference point of the jaw movements was the mid-incisor point of the mandible. Due to the close positional relationship between the attachment site and the reference point, that is the MIPT, the influence of mandibular deformation on the recorded movement of the MIPT is likely to be minimal in this study. However, the accuracy with which condylar movement can be recorded at high closing forces is an important issue. Thus, studies that investigate the association between the condylar movement and the EMG activity at high closing forces (not done in the present study) must address this issue.

5.3.2 The influence of an occlusal alteration on the jaw muscles during laterotrusion (also see Section 4.3.2 for results)

This study investigated the effect of an occlusal alteration on the EMG activity of jaw muscles during “dynamic lateral jaw movements”. The results showed that a working-side occlusal alteration could change the EMG activity in some jaw muscles during laterotrusion. Generally, the findings are consistent with previous studies in the area (Belser and Hannam, 1985; Baba *et al.*, 1996, 2000) which showed that an occlusal alteration (by introducing an occlusal interference) could alter the EMG activity of some jaw-closing muscles in a static lateral clenching “position”.

5.3.2.1 Laterotrusion at the high closing force level with slow speed

Although both previous studies (Belser and Hannam, 1985; Baba *et al.*, 1996) and the present study showed that a working-side occlusal alteration could lead to a reduction in the EMG activity of some jaw-closing muscles, the results of the present study for the holding phase of laterotrusion at the high closing force were not entirely comparable to the previous studies. While clenching in the eccentric lateral position, Belser and Hannam (1985) showed that a working-side canine interference caused a significant reduction in the EMG activity of the bilateral anterior and posterior temporalis and masseter muscles in comparison with clenching in intercuspal position. However, the working-side molar interference in the Belser and Hannam study was associated with minor (i.e. not significantly different) differences in jaw elevator muscle activity, and these were the working-side (ipsilateral) masseter muscles, and the balancing-side (contralateral) anterior and posterior temporalis muscles. Baba and colleagues

(1996) showed that the introduction of a working-side canine raiser tended to decrease the level of jaw-closer EMG activity, with a significantly lower level of activity in the balancing-side masseter (contralateral to the movement) and the working-side anterior and posterior temporalis muscles. However, a working-side molar interference caused only minor differences in muscle activity, and only the non-working (contralateral) side masseter muscle showed a statistically significant reduction in activity.

In the present study, the results in the holding phase of laterotrusion under the high closing force showed that the working-side molar overlay (occlusal alteration) caused a significant reduction in the EMG activity of the bilateral anterior temporalis and masseter muscles. This difference in the results with the earlier studies could be related to the difference in the experimental designs. In the previous studies, the subjects were instructed to clench in a fixed lateral position, whereas in this study, subjects were instructed to move the mandible laterally from the intercuspal position, hold at a lateral position, and then move the mandible back to the intercuspal position. The EMG activity in the holding phase could well be influenced by the different instructions to the subjects concerning these two tasks and/or by the anticipation of the following return movement. Further, the interference part (the palatal slope) of the occlusal alteration in this study was a smooth surface, and no special marks were made to indicate the holding position, while the subjects in the previous studies (Belser and Hannam, 1985; Baba *et al.*, 1996) clenched at a stable static lateral position. Thus, because of the difference in the experimental designs, further comparison between the previous studies and this study is difficult.

Other than the jaw-closing muscles, the present study also showed that an occlusal alteration could change the EMG activity of the IHLP, which is thought to play a major role during laterotrusion. Under the high closing force, the occlusal alteration caused a significantly higher EMG activity in the contralateral IHLP at the outgoing and return phases. Of all the muscles recorded, this is the only muscle that showed a significantly higher activity under the working-side occlusal alteration than those under both control conditions.

5.3.2.2 Possible factors involved in the influence of the occlusal alteration on the EMG activity of jaw muscles

There are several factors that might be involved in the influence of an occlusal alteration on the EMG activity of the jaw muscles during laterotrusion. First is the altered inclination of the tooth guidance. Under the same closing force, a steeper tooth incline would generate a larger force vector which would have a greater tendency to guide the mandible toward the intercuspal position than for a shallower incline. In the present study, the inclinations of the lateral tooth guidance were increased by the occlusal alteration. Therefore, an increase in the lateral force is required to overcome this altered closing vector during lateral jaw movement under the occlusal alteration, and this increase could derive from the IHLP. In the present study, an increase in IHLP EMG activity was indeed observed at the high closing force task. Another possibility could be a decrease in the jaw closing force brought about by a reduction in the activity from the jaw-closing muscles and this was also observed in the present study. An increase in IHLP EMG activity, as observed in the present study, would also be required

during the return phase, to allow the mandible to move back at the same speed and prevent a sudden return of the mandible.

Related to this is the awareness of the overlay by the subjects, although the subjects did not know the possible effects of the occlusal alteration on the jaw muscles. Such awareness might change the movement pattern and muscle activity during lateral movement to overcome the interference.

Second is the altered mandibular and condylar movements. Previous studies (Coffey *et al.*, 1989; Hobo and Takayama, 1989; Sarinnaphakorn *et al.*, 1997; Ogawa *et al.*, 1998) as well as the present study (see Sections 4.2 and 5.2) have shown that an occlusal alteration could change the mandibular and condylar movements during lateral movements. Such a change in movements might have an effect on jaw muscle activity, through reflex changes in EMG activity occasioned by the altered somatosensory input from a range of orofacial afferents, e.g. muscle spindles or TMJ mechanoreceptors. The lateral pterygoid muscles may well be significantly affected here given that IHLP EMG activity shows a high correlation with condylar movements during lateral jaw movement (Murray *et al.*, 1999; Phanachet and Murray, 2000). Further, Uchida and colleagues (2002) showed that the mean EMG activity and the mean firing rates of 21 single motor units were significantly affected by direction in the horizontal plane. In the present study, the occlusal alteration could cause a change in the angle of mandibular movement in the frontal plane ($\sim 10^\circ$). However, the study by Uchida and colleagues (2002) and the present study changed the directions of mandibular movement in different planes, and therefore further studies are

needed. In addition, Manns and colleagues (1981) showed a gradual decrease of EMG activity in anterior and posterior temporalis and masseter muscles with progressively increased vertical dimension from the occlusal vertical dimension. In the present study, at the same amount of MIPT displacement, there was a larger inferior component of the MIPT movement under the occlusal alteration in comparison with that under natural tooth guidance. Therefore, the decrease in EMG activity of bilateral anterior temporalis and masseter muscles under the occlusal alteration, observed in the present study, could also be related to the increased inferior MIPT movement (vertical dimension). It is also possible that the altered EMG activity contributed to the change in mandibular movements.

Another possible sensory receptor affected by the occlusal alteration could be periodontal pressoreceptors that have been shown to cause an alteration in jaw muscle activity under certain conditions, for example, during masticatory movements (Sessle and Gurza, 1982; Lavigne *et al.*, 1987) and as part of the jaw unloading reflex (Turker and Jenkins; 2000). It is very likely that an occlusal alteration changes the periodontal input and leads to reflex changes in the EMG activity of the jaw muscles.

5.3.2.3 Protrusion at the low closing force level (as control movements)

The protrusion recordings in this study were used as control movement data to investigate the possible involvement of time-dependent factors (e.g. muscle fatigue). The data from 10 subjects, in whom the occlusal alteration did not cause any interference during protrusion were taken for comparison under the three occlusal conditions. The results showed that there was a gradual decrease in the

EMG activity in the contralateral IHLP, and the ipsilateral anterior temporalis and masseter muscles under the three occlusal conditions. Although this phenomenon did not happen in all phases during laterotrusion, we could not rule out the possibility of the involvement of time-dependent factors. These data emphasized the importance of the control 2 recordings. Further, as shown in Tables 4.3-4, -8, -9 and -13, after taking the control 2 recordings into consideration (Criterion 2 and 3), fewer subjects showed a significant influence under the occlusal alteration condition. Nonetheless, the principal conclusions of this study, namely an occlusal alteration could influence the EMG activity of some jaw muscles, were still able to be made under the most stringent criterion.

5.3.2.4 The influence of two closing force levels

Because there was a difficulty in controlling or measuring the closing force level in this experiment, we measured the influence of the occlusal alterations under two closing force levels, to see whether the occlusal alteration had similar effects on the EMG activity of the jaw muscles under the two force levels. Generally, the effects of the occlusal alteration on the jaw-closing muscles were very similar at the two force levels. The occlusal alteration under both closing force levels mainly caused a significant reduction in the EMG activity of the ipsilateral jaw-closing muscles. However, the effects on the contralateral IHLP were more variable under the low closing force than those under the high closing force level. Under the low closing force, the occlusal alteration caused a significantly higher IHLP activity under the occlusal alteration in some subjects, whereas it caused a significantly lower IHLP activity in other subjects. Under the high closing force, the occlusal alteration caused a significantly higher activity or no significant

change in the contralateral IHLP activity in all except one subject. Such a variability in IHLP activity between two force levels could be related to the decrease in the requirement of a larger lateral force at the low closing force level task. As previously mentioned, with high closing force, the altered inclination of the tooth guidance may require a larger lateral force to overcome the occlusal alteration, or to prevent the mandible returning to the intercuspal position too quickly. However, with low force to maintain tooth contact, this possible requirement would be less necessary or not necessary. In addition, the periodontal input is likely to be different under the two force level conditions and this changed input could contribute to an altered reflex influence on jaw muscle activity.

Another finding was that under the low closing force, the EMG activity of some muscles under the control 2 condition did not fully return to that under the control 1 condition. These results were interesting given findings from the simultaneously recorded condylar movement data that the working-side condylar path during the return phase under the control 2 condition was significantly different to the control 1 condition (see Sections 4.2.2 and 5.2.2.2). These data suggest the occlusal alteration might have a prolonged effect on the working-side condylar movement and the EMG activity of some jaw muscles. However, whether the altered condylar movement was an influencing factor in the altered EMG activity or whether the altered EMG activity influenced the condylar path remains unclear.

5.3.2.5 The influence of speed of laterotrusion

Our initial assessment of the influence of the occlusal alteration on the EMG activity of the IHLP showed the occlusal alteration mainly caused a significant change in the return phase. One of our hypotheses was that there is a need for a reciprocal force from the IHLP to prevent the mandible returning to the intercuspal position too quickly in the speed-controlled slow movement task. The question arose as to whether this significant change IHLP activity was also apparent in the fast movement task. Therefore, we also recorded the EMG activity under the three occlusal conditions at the fast speed. The results showed that the effect of the occlusal alteration on the jaw muscles within individual subjects under the fast-speed task (that is, whether a significant increase, or decrease, or no change in each muscle) was very similar to that under the slow-speed task with the low closing force. Although some jaw-closing muscles, especially on the working side, showed an overall significantly lower activity at the slow-speed task, because the sample size at the fast-speed task was smaller than that of the slow-speed task, no overall statistically significant difference was shown in all muscles, except for the contralateral masseter at the holding phase and the ipsilateral posterior temporalis at the outgoing phase.

5.3.2.6 Limitations of this study

The major limitation of this study is the uncontrolled non-standardized force levels. However, as previously discussed in Section 5.3.1.5, there is a lack of appropriate equipment or methods to control or standardize the force level in a way that does not alter vertical dimension or interfere with the occlusion at intercuspal position. In addition, it is argued that the closing force level is a

factor that should be "measured" rather than "controlled", because a controlled force level might mask part of the effect of an occlusal alteration. In other words, if the force level was not the same under the natural tooth guidance and occlusal alteration, it could be part of the effect of an occlusal alteration. For example, as previously discussed in Section 5.3.2.2, to overcome a steeper incline of the overlay or prevent a sudden return of the mandible in a speed-standardized movement task, a decrease in the jaw-closing force and/or an increase in the horizontal force might be required. Since the force level might not be independent of the altered occlusal conditions, the force level should not be a "controlled" factor but should be a measured factor. Thus, although an uncontrolled force might cause some variability between trials, a controlled force might be associated with more difficulties in interpretation of the real effect of the occlusal alteration on jaw muscle activity.

On the other hand, an uncontrolled jaw-closing force might have some influence on the results of the activity of the IHLP. For example, at a higher closing force level, a larger closing force might help to prevent the mandible from going outward or might help to pull the mandible back during the lateral movements. Therefore, it would presumably require a higher output from the contralateral IHLP to pull the mandible outward during the outgoing phase as an agonist, and to prevent the mandible from going back too fast at the return phase as an antagonist in our speed controlled tasks. However, the uncontrolled jaw-closing force did not change our essential conclusions at the high closing force, namely that the occlusal alteration caused a higher EMG activity in the IHLP especially in the return phase. Our results indicated that, in all subjects except one, there

was a significantly lower jaw-closer EMG activity or no influence on the activity of the jaw-closing muscles under the occlusal alteration condition. If this difference in the effect on jaw-closing muscles in different subjects was caused by the uncontrolled vertical force level, the subjects with the lower jaw closer activity might be associated with a reduced output from the contralateral IHLP, which was not the case in our study especially in the return phase.

Nonetheless, there is no doubt that an “unstandardized” force level might cause some problems in the interpretation of the data. Subjects might just apply less closing force under the occlusal alteration due to other reasons and not due to the occlusal alteration. Therefore, as indicated earlier, the force level should be “measured”. When appropriate equipment is available, further studies are needed on this issue.

The second limitation of the present study was the use of surface electrodes in recording the EMG activity of the masseter and temporalis muscles, which have a complex architecture (for further discussion, see Section 5.3.1.5). Further studies are needed on the influence of an occlusal alteration on different components of these muscles.

The third limitation of this study was the use of a working-side molar overlay as the occlusal alteration. According to Belser and Hannam (1985) and Baba and coworkers (1996, 2000), a balancing-side molar interference has larger effects on the jaw muscle activity than a working-side canine interference, and a working-side canine interference has a larger effect on the jaw muscle activity than a

working-side molar interference. However, difficulty was experienced in initial attempts to fabricate a balancing-side molar interference in such a way that there was no increase in vertical dimension in the intercuspital position (Belser and Hannam, 1985). In the present study, any interference from the occlusal alteration preventing closure into the intercuspital position was avoided. Another problem was that a working-side canine interference could cause some interference with the clutches of our jaw-tracking device. Therefore, in this study, we used a working-side molar interference. Further studies on the other two types of the interference are needed.

The fourth limitation of this study is the low sample size; therefore, it is difficult to divide subjects into subgroups for further discussion. As a pilot study in this field, our results showed that an occlusal alteration could significantly change the EMG activity of some jaw muscles during laterotrusion. However, the effect of the occlusal alteration on the EMG activity is variable between subjects especially at low closing forces. This variability could be related to individual differences such as age, gender, occlusal form, jaw morphology, and so on. Further studies would be needed to investigate the influence of these individual factors.

5.3.2.7 Functional heterogeneity within IHLP

The IHLP has been arbitrarily divided into four regions (supero-medial, supero-lateral, infero-medial and infero-lateral) by Phanachet and colleagues (2001) who reported that the single motor units recorded in the supero-medial zone exhibited significantly lower mean threshold values than those in the other zones. This

provided suggestive evidence supporting previously proposed notions of functional heterogeneity within IHL. Some very preliminary data was provided in the present study that suggested different effects of the occlusal alteration on different parts of the IHL. Thus, at the high closing force, four of five subjects showed a significantly higher activity on the return phase under the occlusal alteration in the supero-medial zone while only one of three did so in the infero-medial zone. The small sample size precludes any definitive statements here and further studies are needed on this issue.

5.3.2.8 A comparison between the results of normalization methods

In the present study, two methods for normalizing EMG activity were used: one was based on the timing of the movement (entire phase) and the other was based on the amount of the MIPT movement (at the 3rd mm of the MIPT movement). However, the results between these two methods were different. For example, the overall comparison at the high closing force showed that the EMG activity of the IHL had a significantly higher activity under occlusal alteration during the entire outgoing phase, but there was no significant difference between the three occlusal conditions at the 3rd mm of outgoing laterotrusion. Additionally, the individual comparison at the low closing force with slow speed showed that two subjects had a significantly higher activity at the 3rd mm of MIPT displacement during the return phase and a significantly lower activity for the entire return phase.

The EMG activity of the entire phase shows the overall influence of the occlusal alteration, but it may over-generalize the results. The EMG activity at a selected

position provides detailed information during the movement, but it cannot represent the influence during the entire phase. Therefore, both methods are suggested for future studies. This preliminary study applied both methods in analyzing the influence of an occlusal alteration on IHLP activity. The IHLP was chosen because previous studies (Murray *et al.*, 1999; Phanachet and Murray, 2000) showed that the EMG activity of the lateral pterygoid muscles exhibited a high correlation coefficient with the condylar movements during lateral jaw movement. The EMG results, normalized based on the amount of MIPT displacement, showed that the most predominant change in IHLP activity due to the occlusal alteration occurred when the MIPT was about 2 – 4 mm away from the intercuspal position in most of the subjects. Therefore, further studies regarding whether this phenomenon happens in the other jaw muscles are suggested.

5.3.2.9 Comparison between the influence of an occlusal alteration on jaw muscle activity and working-side condylar head movement

In the present study, we recorded the EMG activity and working-side condylar movement simultaneously under the three occlusal conditions in some subjects. The results showed a more inferior and anterior component of the working-side condylar path and a significantly lower activity on the jaw-closing muscles under the occlusal alteration. Although the more inferior displacement of the working-side condylar movement might be associated with the decreased activity in the jaw-closing muscles, the net contribution of these jaw-closing muscles on the mandibular and condylar movements is complex and could be addressed through Finite Element studies. Further, although the results showed a significantly

higher activity on the contralateral IHLP under the occlusal alteration at the high closing force in comparison with the control, there was no significant difference in the IHLP activities at the low closing force. Interpretation of the relation between the altered IHLP activity (at high closing force) and the working-side condylar paths (at low closing force) cannot be done at present. This is because the issue of mandibular deformation at the high closing force precludes an assessment of the influence of an occlusal alteration on the working-side condylar paths at the high-closing force.

5.3.2.10 Clinical significance and future studies

Controversy continues regarding the relationship between occlusion and temporomandibular disorders (TMD; for reviews, see De Boever *et al.*, 2000a, b) and regarding the use of occlusal adjustments as a treatment for TMD or a prophylactic procedure (Kirveskari *et al.*, 1998; Kirveskari and Alanen, 2000; Seligman and Pullinger, 2000; Pullinger and Seligman, 2000). Clark and colleagues (1999) reviewed 28 articles published between 1931 to 1999, and concluded that an experimental occlusal interference could induce transient localized tooth pain, tooth loosening, slight changes in postural muscle tension levels, or changes in chewing stroke patterns, and sometimes a clicking TMJ. As such findings are present in asymptomatic patients, the authors (Clark *et al.*, 1999) stated that these data do not prove that occlusal interferences are causally related to TMD. Whether or not occlusal interferences play a role in TMD is beyond the scope of this thesis, nonetheless, if the occlusion does play even a minor role in TMD, then changes to the occlusion should be capable of changing condylar movement and jaw muscles activity. The present study has provided

clear evidence that a change in the occlusion could significantly influence EMG activity of the jaw muscles, in particular the lateral pterygoid muscle. This muscle plays a crucial role in TMJ movement. However, whether such a change might play a role in TMD is unclear and requires further study. It is important to note that this study was not designed to investigate the relationship between an occlusal alteration and TMD nor the validity of occlusal adjustment. Research is needed to determine whether a change in condylar movement and jaw muscles activity due to an occlusal alteration has any role in the aetiology or exacerbation of TMD.

The present study investigated the "immediate" effect of an occlusal alteration on the EMG activity of jaw muscles, and the long-term effects remain unclear. The changes in muscle activity reported here may not be apparent with long-term changes to the occlusion, since these muscles may adapt to the occlusal alteration. Indeed, it appears that in routine clinical practice, the jaw muscle system, and the TMJs in particular, adapt to alterations to the occlusion without clinical problems arising. It is possible however that in some individuals the jaw muscle system may not adapt to such changes. Further studies are clearly needed. The present study has provided evidence for the first step towards this issue by showing that a change in the occlusion alters both EMG activity of some jaw muscles and condylar movement.

The results of this research showed that the occlusal alteration in the present study, a steepened incline of the posterior tooth guidance, caused a significantly higher activity in the contralateral IHLP. Our data also showed that this occlusal

alteration caused a reduction in EMG activity of the anterior temporalis and masseter muscles bilaterally, especially on the ipsilateral side. However, the present study did not investigate the relevance of occlusal adjustment to reduce the inclination.

Our results showed that an occlusal alteration could cause a significantly higher activity in the contralateral IHLP at a high-closing-force laterotrusion. This raises the question for people with "*existing*" grinding habits, whether the introduction of an occlusal alteration could increase the loading of the contralateral IHLP. However, in this study, lateral jaw movements at high closing force was a voluntary movement controlled by the subjects, and therefore, the results might be different to involuntary tooth grinding and bruxism.

6 Conclusion

The results of this study support our hypothesis that a change to the occlusion has an immediate effect on temporomandibular joint function during laterotrusion, in terms of working-side condylar movements and jaw muscle EMG activity.

The first aim of this study was to develop an indirect method to register the coordinates of anatomical condylar points in the coordinate system of JAWS-3D and to test the accuracy of this method. The results showed that the indirect method could register condylar point coordinates on either side of the face to an accuracy of ~ 0.5 mm.

The second aim was to investigate the influence of an occlusal alteration (working-side, increased inclination of 10°) on the working-side condylar tracings during lateral jaw movements. The results showed that the paths of the multiple working-side condylar points under the occlusal alteration were significantly more anterior and inferior to those under the control conditions at the same amount of mid-incisor point displacement during the outgoing and return phases. In addition, our results showed that occlusal alteration could significantly change the rotation angles of the mandible during both phases. The selection of the condylar points changed the statistical results of the comparison between the control 1 and occlusal alteration conditions, especially during the return phase, and this emphasized the importance of the location of the condylar point in describing condylar motion especially on the working side.

The third aim was to investigate the EMG activity of some jaw muscles during lateral jaw movements. Under the low closing force with slow speed, among the nine muscles recorded, the contralateral inferior head of the lateral pterygoid muscle was the only muscle that showed a clear increase in the EMG activity throughout the outgoing, holding and returning phases of laterotrusion when all subjects were analyzed together. The contralateral anterior and posterior temporalis muscles showed a decrease in activity from the original activity level at intercuspal position 1 phase. In the ipsilateral anterior and posterior temporalis and bilateral masseter muscles, more than one type of EMG activity pattern were shown. Under a high closing force, the EMG activities of the contralateral inferior head of the lateral pterygoid muscle and bilateral anterior temporalis and masseter muscles were significantly higher than those under the low closing force. Under a fast speed, the EMG activity of the contralateral inferior head of the lateral pterygoid muscle during the outgoing phase was significantly higher than that under the low closing force with slow speed, whereas the activity of the contralateral inferior head of the lateral pterygoid muscle during the return phase and the activity of the contralateral anterior temporalis during the outgoing phase were significantly lower.

The fourth aim was to investigate the influence of an occlusal alteration on jaw muscle activity during laterotrusion. Under occlusal alteration at the high-closing-force laterotrusion, bilateral anterior temporalis and masseter muscles showed a lower activity, especially on the ipsilateral (working) side, while the EMG activity in the contralateral inferior head of the lateral pterygoid muscle was higher, especially at the return phase. There was no significant effect on the

bilateral posterior temporalis and submandibular muscles in most subjects. Protrusion recordings, as control movement data, suggested an involvement of time-dependent factors (e.g. muscle fatigue) in some trials which underscores the importance of the control 2 recordings. Generally, the effects of the occlusal alteration on the jaw-closing muscles was very similar at the two closing force levels. However, the effects on the contralateral inferior head of the lateral pterygoid muscle were more variable under the low closing force than those under the high closing force. The results showed that the comparison within individual subjects under the fast-speed task with low closing force was very similar to that under the slow-speed task with low closing force.

The results support our hypothesis that a change in the occlusion on the working side had an "immediate" effect on jaw function, both in terms of statistically significant effects on the condylar head movement and on the activity of some jaw muscles.

7 Bibliography

1. Ahlgren J. (1966) Mechanism of Mastication. *Acta Odontol Scand* 24: (Suppl 44).
2. Ahlgren J. (1976) Masticatory movements in man. In: Mastication. Anderson DJ, Matthews B, editors. Bristol, England: John Wright and Sons LTD, pp. 119-129.
3. Airola RL, Gallo LM, Palla S. (1994) Precision of the jaw tracking system JAWS-3D. *J Orophac Pain* 8: 155-164.
4. Alsawaf MM, Garlapo DA. (1992) Influence of tooth contact on the path of condylar movements. *J Prosthet Dent* 67: 394-400.
5. Ash MM, Ramfjord S. (1995) Occlusion. 4th ed. Philadelphia: W.B. Saunders Company, pp77-83.
6. Baba K, Ai M, Mizutani H, Enosawa S. (1996) Influence of experimental occlusal discrepancy on masticatory muscle activity during clenching. *J Oral Rehabil* 23: 55-60.
7. Baba K, Yugami K, Akishige S, Ai M. (2000) Immediate effect of occlusal contact pattern in lateral jaw position on the EMG activity in jaw-elevator muscles in humans. *Int J Prosthodont* 13: 500-505.
8. Bates JF, Stafford GS, Harrison A. (1975) Masticatory function – A review of the literature. I: The form of the masticatory cycle. *J Oral Rehabil* 2: 281-301.
9. Belser UC, Hannam AG. (1985) The influence of altered working-side occlusal guidance on masticatory muscles and related jaw movement. *J Prosthet Dent* 53: 406-413.
10. Bertilsson O, Ström D. (1995) A literature survey of a hundred years of anatomic and functional lateral pterygoid muscle research. *J Orophac Pain* 9: 17-23.
11. Bittar GT, Bibb CA, Pullinger AG. (1994) Histologic characteristics of the lateral pterygoid muscle insertion to the temporomandibular joint. *J Orophac Pain* 8: 243-249.
12. Blanksma NG, van Eijden TM. (1990) Electromyographic heterogeneity in the human temporalis muscle. *J Dent Res* 69: 1686-1690.
13. Blanksma NG, van Eijden TM, Weijs WA. (1992) Electromyographic heterogeneity in the human masseter muscle. *J Dent Res* 71: 47-52.

14. Borromeo GL, Suvinen TI, Reade PC. (1995) A comparison of the effects of group function and canine guidance interocclusal device on masseter muscle electromyographic activity in normal subjects. *J Prosthet Dent* 74: 174-180.
15. Carlsöö S. (1956) An electromyographic study of the activity, and an anatomic analysis of the mechanics of the lateral pterygoid muscle. *Acta Anat* 26: 339-351.
16. Clark GT, Tsukiyama Y, Baba K, Watanabe T. (1999) Sixty-eight years of experimental occlusal interference studies: what have we learned? *J Prosthet Dent* 82: 704-713.
17. Clayton JA, Mahan PE, Myers GE. (1971) Graphic recording of mandibular movements: research criteria. *J Prosthet Dent* 25: 287-298.
18. Coffey JP, Kotoqicz WE, Gibbs CH, Welsch BB. (1989) A preliminary study of the effects of tooth guidance on working-side condylar movement. *J Prosthet Dent* 62 : 157-162.
19. Colaizzi FA, Michael CG, Javid NS, Gibbs CH. (1988) Condylar and incisal border movements: A comparative study of complete denture wearers and natural dentition subjects. *J Prosthet Dent* 59: 453-459.
20. Dawson PE. (1989) Centric relation. In: Evaluation, diagnosis, and treatment of occlusal problems, 2nd ed, St. Louis: The C. V. Mosby Company, pp. 28-55.
21. De Boever JA, Carlsson GE, Klineberg IJ. (2000a) Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part I. Occlusal interferences and occlusal adjustment. *J Oral Rehabil* 27: 367-379.
22. De Boever JA, Carlsson GE, Klineberg IJ. (2000b) Need for occlusal therapy and prosthodontic treatment in the management of temporomandibular disorders. Part II. Tooth loss and prosthodontic treatment. *J Oral Rehabil* 27: 647-659.
23. De Pietro AJ. (1963) Concepts of occlusion. A system based on rotational centers of the mandible. *Dent Clin North Am* 607-620.
24. Dorland WAN. (2000) Dorland's Electronic Medical Dictionary, 29th ed, Philadelphia: W.B. Saunders Company.
25. DuBrul EL. (1988) Sicher and DuBrul's oral anatomy. 8th ed. Tokyo: Ishiyaku EuroAmerica, Inc.
26. Dupas PH, Picart B, Graux F, Lefevre C. (1987) Effect of clutch surface changes on the computerized pantographic reproducibility index and the Fischer angle. *J Prosthet Dent* 57: 625-630.

27. Ebert H. (1939) Morphologische und Functionelle des Musculus Masseter. *Z Anat Entw Gesch* 109: 790-802.
28. Ekfeldt A, Karlsson S. (1996) Changes of masticatory movement characteristics after prosthodontic rehabilitation of individuals with extensive tooth wear. *Int J Prosthodont* 9: 539-546.
29. Eriksson PO, Zafar H, Nordh E. (1998) Concomitant mandibular and head-neck movements during jaw opening-closing in man. *J Oral Rehabil* 25: 859-870.
30. Gallo LM, Nickel JC, Iwasaki LR, Palla S. (2000) Stress-field translation in the healthy human temporomandibular joint. *J Dent Res* 79:1740-1746.
31. Gardner E, Gray DJ, O'Rahilly R. (1963) *Anatomy*. 2nd ed. Philadelphia: W. B. Saunders Co., pp. 845-847.
32. Gibbs CH, Lundeen HC. (1982) Jaw movements and forces during chewing and swallowing and their clinical significance. In: *Advances in occlusion*. Lundeen HC, Gibbs CH, editors. Littleton: John Wright & Sons, pp 2 -32.
33. Gibbs CH, Mahan PE, Wilkinson TM, Mauderli A. (1984) EMG activity of the superior belly of the lateral pterygoid muscle in relation to other jaw muscles. *J Prosthet Dent* 51: 691-702.
34. Gibbs CH, Messerman T, Teswick JB. (1971) Functional movement of the mandible. *J Prosthet Dent* 26: 604-620.
35. Goodkind RJ, Heringlake CB. (1972) Mandibular flexure in opening and closing movements. *J Prosthet Dent* 30:134-138.
36. Grant AA. (1986) Some aspects of mandibular movement: acceleration and horizontal distortion. *Annals of the Academy of Medicine, Singapore*. 15: 305-310.
37. Grant PG. (1973) Lateral pterygoid: two muscles? *Am J Anat* 138: 1-9.
38. Gross MD, Hirsh N. (1985) Investigation of the effect of a variable anterior guidance incline on the graphic registration of the mandibular border movement: Part I. *J Prosthet Dent* 53: 731-736.
39. Gross MD, Nemcovsky CE. (1993) Investigation of the effect of a variable anterior guidance incline on the graphic registration of the mandibular border movement: Part II. *J Prosthet Dent* 70: 336-344.
40. Gysi A. (1910) The problem of articulation. *Dent Cosmos* 52: 1-19, 148-169, 403-418.
41. Hagiwara M, Koriath TWP, Hannam AG. (1994) The effect of vertical dimension of on condylar movement. *J Dent Res* 73: 263.

42. Hannam AG (1992) The measurement of jaw motion. In : Current controversies in temporomandibular Disorders. McNeill C, editor. Chicago: Quintessence, pp 130-137.
43. Hannam AG. (1994) Musculoskeletal biomechanics in the human jaw. In : Temporomandibular joint and masticatory muscle disorders. 2nd ed. Zarb GA, Carlsson GE, Sessle BJ, Mohl ND, editors. Copenhagen: Munksgaard, pp. 101-127.
44. Hannam AG, McMillan AS. (1994) Internal organization in the human jaw muscles. *Crit Rev Oral Biol Med* 5: 55-89.
45. Hannam AG, Wood WW, De Cou RE, Scott JD. (1981) The effects of working-side occlusal interferences on muscle activity and associated jaw movements in man. *Arch Oral Biol* 26: 387-392.
46. Hansson T, Nordstrom B. (1977) Thickness of the soft tissue layers and articular disc in temporomandibular joints with deviation in form. *Acta Odontol Scand* 35: 77-83.
47. Hansson T, Oberg T. (1977) Arthrosis and deviation in form in the temporomandibular joint: a microscopic study on human autopsy material. *Acta Odontol Scand* 35: 167-74.
48. Hiraba K, Hibino K, Hiranuma K. (1995) Reciprocal activities of the two heads of the human lateral pterygoid muscle. In: Brain and oral functions. Morimoto T, Matsuya T, Takada K, editors. New York: Elsevier Science B.V. pp. 499-505.
49. Hobo S. (1984) A kinematic investigation of mandibular border movement using an electronic measuring system. part II: a study of Bennett movement. *J Prosthet Dent* 51: 642-646.
50. Hobo S, Mochizuki S. (1983) A kinematic investigation of mandibular border movement using an electronic measuring system. part I: development of the measuring system. *J Prosthet Dent* 50: 368-373.
51. Hobo S, Takayama H. (1989) Effect of canine guidance on the working condylar path. *Int J Prosthodont* 2: 73-79.
52. Honée GLJM. (1972) The anatomy of the lateral pterygoid muscle. *Acta Morphol Neerl Scand* 10: 331-340.
53. Hylander WL. (1988) Implications of in vivo experiments for interpreting the functional significance of "robust" australopithecine jaws. In: Evolutionary History of the "Robust" Australopithecine, Grine FE, editor. New York: Aldine de Gruyter, pp. 55-83.

54. Hylander WL. (1992) Functional anatomy. In: The temporomandibular joint. 4th ed. Sarnat BG, Laskin DM, editors. Philadelphia: W.B. Saunders Company, pp. 60-92.
55. Ingervall B. (1972) Range of sagittal movement of the mandibular condyles and inclination of the condyle path in children and adults. *Acta Odontol Scand* 30: 67-87.
56. Jiang T. (1992) Condylar displacement and mandibular bending deformation due to bite force. *Kokubyo Gakkai Zasshi, Japan*. 59:142-159.
57. Kamimura Y. (1983) The effect of the central bearing plate form on the Fischer angle. *J Gnathol* 2: 45-54.
58. Kirveskari P, Alanen P. (2000) Occlusal variables are only moderately useful in the diagnosis of temporomandibular disorder. *J Prosthet Dent* 84: 114-115.
59. Kirveskari P, Jamsa T, Alanen P. (1998) Occlusal adjustment and the incidence of demand for temporomandibular disorder treatment. *J Prosthet Dent* 79: 433-438.
60. Klineberg IJ. (1991a) The lateral pterygoid muscle: some anatomical, physiology and clinical consideration. *Ann R Aust Coll Dent Surg* 11: 96-108.
61. Klineberg IJ. (1991b) Occlusion: Principles and Assessment: Boston: Wright (Butterworth-Heinemann Ltd).
62. Koriath TWP, Hannam AG. (1994) Deformation of the human mandible during simulated tooth clenching. *J Dent Res* 73: 56-66.
63. Krebs M, Gallo LM, Airoidi RL, Meier D, Boesiger P, Palla S. (1994) Three-dimensional animation of the temporomandibular joint. *Technol Health Care* 2: 193-207.
64. Krebs M, Gallo LM, Airoidi RL, Palla S. (1995) A new method for three-dimensional reconstruction and animation of the temporomandibular joint. *Ann Acad Med Singapore*, 24: 11-16.
65. Krenkel CH, Grunert I. (1988) Die Kiefer-Kondylen in der Run-strom-IV-Rontgenansicht. *Z Stomatol* 85: 135-153.
66. Lam EW, Hannam AG, Christiansen EL. (1991) Estimation of tendon-plane orientation within human masseter muscle from reconstructed magnetic resonance images. *Arch Oral Biol* 36: 845-853.
67. Landa JS. (1958) A critical analysis of the Bennett movement. *J Prosthet Dent* 8: 709-726.

68. Lavigne G, Kim JS, Valiquette C, Lund JP. (1987) Evidence that periodontal pressoreceptors provide positive feedback to jaw closing muscles during mastication. *J Prosthet Dent* 50: 710-718.
69. Lundeen HC, Shryock EF, Gibbs CH. (1978) An evaluation of mandibular border movements: Their character and significance. *J Prosthet Dent* 40: 442-452.
70. Mahan PE, Wilkinson TM, Gibbs CH, Mauderli A, Brannon LS. (1983) Superior and inferior bellies of the lateral pterygoid muscle EMG activity at basic jaw positions. *J Prosthet Dent* 50: 710-718.
71. Manns A, Chan C, Miralles R. (1987) Influence of group function and canine guidance on electromyographic activity of elevator muscles. *J Prosthet Dent* 57: 494-501.
72. Manns A, Miralles R, Guerrero F. (1981) The changes in electrical activity of the postural muscles of the mandible upon varying the vertical dimension. *J Prosthet Dent* 45: 438-445.
73. McCollum BB. (1939) Fundamentals involved in prescribing restorative dental remedies. *Dent Items interest* 61: 532-535, 641-648, 724-736, 852-863, 942-950.
74. McNamara JA Jr. (1973) The independent functions of the two heads of the lateral pterygoid muscle. *Am J Anat* 138: 197-206.
75. Merlini L, Palla S. (1988) The relationship between condylar rotation and anterior translation in healthy and clicking temporomandibular joints. *Schweiz Monatsschr Zahnmed* 98: 1191-1199.
76. Mesqui F, Kaeser F, Fischer P. (1985) Real-time, non-invasive recording and three-dimensional display of the functional movements of an arbitrary mandible point. *Proceedings of SPIE* 602: 77-84.
77. Miller AJ. (1991) *Craniomandibular Muscles: Their role in function and form*. Boca Raton: CRC Press pp. 1-110.
78. Mohl ND. (1988) The temporomandibular joint. In: *A textbook of occlusion*, Mohl ND, Zarb GA, Carlsson GE, Rugh JD, editors. Chicago: Quintessence Publishing Co., Inc. pp. 81-96.
79. Mongini F, Capurso U. (1982) Factors influencing the pantographic tracings of mandibular border movements. *J Prosthet Dent* 48: 585-598.
80. Murray GM, Orfanos T, Chan JY, Wanigaratne K, Klineberg IJ. (1999) Electromyographic activity of the human lateral pterygoid muscle during contralateral and protrusive jaw movements. *Arch Oral Biol* 44: 269-285.

81. Murray GM, Phanachet I, Uchida S, Whittle T. (2001) The role of the human lateral pterygoid muscle in the control of horizontal jaw movements. *J Orofac Pain* 15: 279-292.
82. Naeije M, Huddleston Slater JJ, Lobbezoo F. (1999) Variation in movement traces of the kinematic center of the temporomandibular joint. *J Orofac Pain* 13: 121-127.
83. Naeije M, van der Weijden JJ, Megens CCEJ. (1995) OKAS-3D: an optoelectronic jaw movement analysis system with six degrees of freedom. *Med Biol Eng Comput* 1995; 33: 683-688.
84. Nielsen I, Miller AJ. (1988) Response patterns of craniomandibular muscles with and without alteration in sensory feedback. *J Prosthet Dent* 59: 352-362.
85. Okeson JP. (1998) Mechanics of mandibular movement. In: *Management of temporomandibular disorders and occlusion*. 4th ed. St Louis, MO: Mosby-Year Book Inc, pp. 93-108.
86. Omar R, Wise MD. (1981) Mandibular flexure associated with muscle force applied in the retruded axis position. *J Oral Rehabil* 8: 209-221.
87. Orfanos T, Sarinnaphakorn L, Murray GM, Klineberg IJ. (1996) Placement and verification of recording electrodes in the superior head of the human lateral pterygoid muscle. *Arch Oral Biol* 41, 493-503.
88. Ogawa M, Ogawa T, Koyano K, Suetsugu T. (1998) Effect of altered canine guidance on condylar movement during laterotrusion. *Int J Prosthodont* 11: 139-144.
89. Page HL. (1955) Occlusal movements and obstructions. Part One. *Dent Digest* 61: 344-350.
90. Palla S, Krebs M, Gallo LM. (1997) Jaw tracking and temporomandibular joint animation. In: McNeill C. editor, *Science and Practice of Occlusion*. Quintessence: Illinios, pp. 365-378.
91. Peck CC, Murray GM, Johnson CWL, Klineberg IJ. (1997) The variability of condylar point pathways in open-close jaw movements. *J Prosthet Dent* 77: 394-404.
92. Peck CC, Murray GM, Johnson CWL, Klineberg IJ. (1999a) Trajectories of condylar points during working-side excursive movements of the mandible. *J Prosthet Dent* 81: 444-452.
93. Peck CC, Murray GM, Johnson CWL, Klineberg IJ. (1999b) Trajectories of condylar points during nonworking-side and protrusive movements of the mandible. *J Prosthet Dent* 82: 322-331.

94. Peck CC, Shoji N, Silva I, Murray GM, Klineberg IJ. (1992) Relationship between condylar rotation and translation in the human temporomandibular joint (abstract). *J Dent Res* 71: 990.
95. Pelletier LB, Campbell SD. (1990) Evaluation of the relationship between anterior and posterior functionally disclusive angles. Part I. Literature review: Instrumentation and reproducibility. *J Prosthet Dent* 63: 395-403.
96. Phanachet I. (2002) Single motor unit activity of the human lateral pterygoid muscle during defined tasks. {PhD(Dent) thesis} Sydney, NSW: University of Sydney.
97. Phanachet I, Murray GM. (2000) Human lateral pterygoid muscle activity on the return phase of contralateral and protrusive jaw movements. *Arch Oral Biol* 45: 517-529.
98. Phanachet I, Whittle T, Wanigaratne K, Murray GM. (2001) Functional properties of single motor units at verified sites in the inferior head of the human lateral pterygoid muscle: task relations and threshold for recruitment. *J Neurophysiol* 86: 2204-2218.
99. Phanachet I, Whittle T, Wanigaratne K, Murray GM. (2002) Functional properties of single motor units in the inferior head of human lateral pterygoid muscle: task firing rates. *J Neurophysiol* 88: 751-760.
100. Phanachet I, Whittle T, Wanigaratne K, Klineberg IJ, Sessle BJ, Murray GM. (2003) Functional heterogeneity in superior head of human lateral pterygoid. *J Dent Res* (*in press*).
101. Porter MR. (1970) The attachment of the lateral pterygoid muscle to the meniscus. *J Prosthet Dent* 24: 555-562.
102. Posselt U. (1952) Studies in the mobility of the human mandible. *Acta Odontol Scand* 10: (suppl 10).
103. Pullinger AG, Seligman DA. (2000) Quantification and validation of predictive values of occlusal variables in temporomandibular disorders using a multifactorial analysis. *J Prosthet Dent* 83: 66-75.
104. Rocabado M. (1983) Arthokinematics of the temporomandibular joint. *Dent Clin North Am* 27: 573-594.
105. Rohrer FA, Palla S, Engelke W. (1991) condylar movements in clicking joints before and after arthrography. *J Oral Rehabil* 18: 111-123.
106. Rugh JD, Johnson RW. (1988) Mandibular movements. In: A textbook of occlusion. Mohl ND, Zarb GA, Carlsson GE, Rugh JD, editors. Chicago: Quintessence Publishing Co., Inc. pp. 129-141.

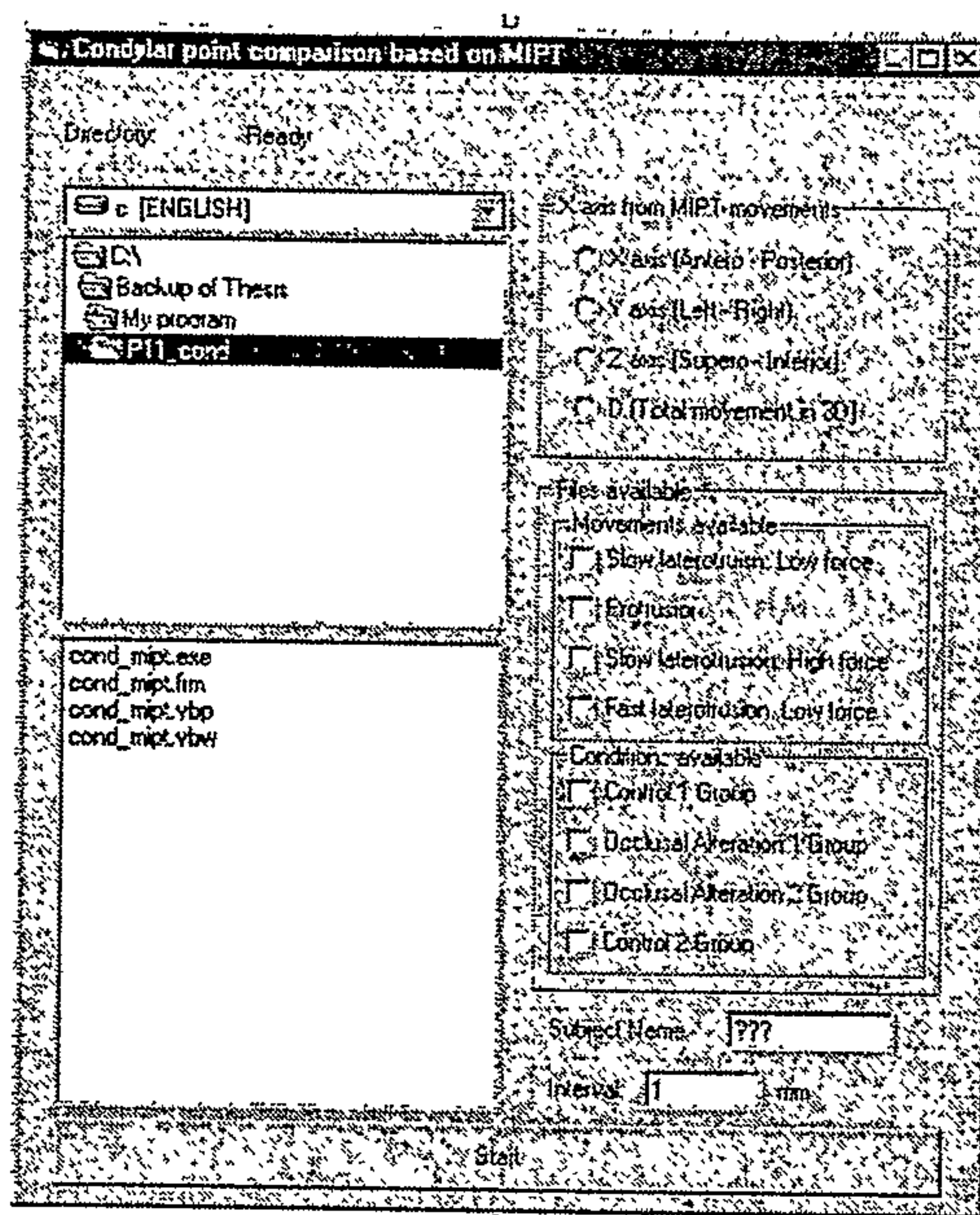
107. Salaorni C, Palla S. (1994) Condylar rotation and anterior translation in healthy human temporomandibular joints. *Schweiz Monatsschr Zahnmed* 104: 415-422.
108. Sarinnaphakorn L. (1997) A study of the effect of posterior tooth guidance on condylar point movement. {MSc(Dent) thesis} Sydney, NSW: University of Sydney.
109. Sarinnaphakorn L, Murray GM, Johnson CWL, Klineberg IJ. (1997) The effect of posterior tooth guidance on non-working side arbitrary condylar point movement. *J Oral Rehabil* 24: 678-690.
110. Schmolke C. (1994) The relationship between the temporomandibular joint capsule, articular disc and jaw muscles. *J Anat* 184: 335-345.
111. Schulte JK, Wang SH, Erdman AG, Anderson GC. (1985) Working condylar movement and its effect on posterior occlusal morphology. *J Prosthet Dent* 54: 118-121.
112. Schumacher G-H. (1961) *Funktionelle Morphologie der Kaumusculatur*. Gustav Fischer Verlag, Jena.
113. Seligman DA, Pullinger AG. (2000) Occlusal variables are only moderately useful in the diagnosis of temporomandibular disorder. Reply. *J Prosthet Dent* 84: 114-115.
114. Sessle BJ, Gurza SC. (1982) Jaw movement-related activity and reflexly induced changes in the lateral pterygoid muscle of the monkey *Macaca fascicularis*. *Arch Oral Biol* 27: 167-173.
115. Shiau YY, Ash MM Jr. (1989) Immediate and delayed effects of working interferences on EMG and jaw movements. In: *Electromyography of jaw reflexes in man*. Van Steenberghe D, De Laat A, editors. Belgium: Leuven University Press, pp. 319-326.
116. Shiau YY, Syu JZ. (1995) Effect of working side interferences on mandibular movement in bruxers and non-bruxers. *J Oral Rehabil* 22: 145-151.
117. Siegler S, Hayes R, Nicolella D, Fielding A. (1991) A technique to investigate the three-dimensional kinesiology of the human temporomandibular joint. *J Prosthet Dent* 65: 833-839.
118. Slavicek R. (1988) Clinical and instrumental functional analysis for diagnosis and treatment planning. Part 5: Axio-graph. *J Clinical Orthod* 22: 656-667.
119. Sohn BW, Miyawaki S, Noguchi H, Takada K. (1997) Changes in jaw movement and jaw closing muscle activity after orthodontic correction of incisor crossbite. *Am J Orthod Dentofacial Orthop* 112: 403-409.

120. Solberg WK, Hansson TL, Norstrom B. (1985) The temporomandibular joint in young adults at autopsy: morphologic classification and evaluation. *J Oral Rehabil* 12: 303-321.
121. Soneda K. (1989) Effect of lingual surface inclination of maxillary canine on jaw muscle activity. *Kokubyo Gakkai Zasshi* 56: 162-181.
122. Stålberg E, Eriksson PO. (1987) A scanning electromyographic study of the topography of human masseter single motor units. *Arch Oral Biol* 32: 793-797.
123. Swintara W, Johnson CWL, Murray GM, Huang BY. (2001) The accuracy with which the human condyle can be expressed in the coordinate system of JAWS3D using a unilateral fiducial marker. *J Oral Rehabil* 28: 33-40.
124. Travell JG, Simons DG. (1983) Lateral (External) pterygoid muscle "TMJ-dysfunction". In: *Myofascial pain and dysfunction: the trigger point manual*. Baltimore: William & Wilkins, pp. 260-272.
125. Turker KS, Jenkins M. (2000) Reflex responses induced by tooth unloading. *J Neurophysiol* 84: 1088-1092.
126. Ten Cate AR. (1994) Gross and micro anatomy. In: *Temporomandibular joint and masticatory muscle disorders*. Zarb GA, Carlsson GE, Sessle BJ, Mohl ND, editors. 2nd ed. Copenhagen: Munksgaard. pp. 48-66.
127. The Glossary of Prosthodontic Terms – Seven Edition. (1999) *J Prosthet Dent* 81: 39-110.
128. Thomson H. (1990) Occlusion. 2nd ed. London: Wright.
129. Uchida S, Whittle T, Wanigaratne K Murray GM. (2001) The role of the inferior head of the human lateral pterygoid muscle in the generation and control of horizontal mandibular force. *Arch Oral Biol* 46: 1127-1140.
130. Uchida S, Whittle T, Wanigaratne K Murray GM. (2002) Activity in the inferior head of the human lateral pterygoid muscle with different directions of isometric force. *Arch Oral Biol* 47: 771-778.
131. van Eijden TM, Blanksma NG, Brugman P. (1993) Amplitude and timing of EMG activity in the human masseter muscle during selected motor tasks. *J Dent Res* 72: 599-606.
132. van Eijden TM, Raadsheer MC. (1992) Heterogeneity of fiber and sarcomere length in the human masseter muscle. *Anat Rec* 232: 78-84.
133. Vaughan CL. (1982) Smoothing and differentiation of displacement data: an application of splines and digital filtering. *Int J Biomed Comput* 14: 375-386.

134. Vitti M, Basmajian JV. (1977) Integrated actions of masticatory muscles: simultaneous EMG from eight intramuscular electrodes. *Anat Rec* 187: 173-189.
135. Widmalm SE, Lillie JH, Ash MM Jr. (1987) Anatomical and electromyographic studies of the lateral pterygoid muscle. *J Oral Rehabil* 14: 429-446.
136. Widmalm SE, Lillie JH, Ash MM Jr. (1988) Anatomical and electromyographic studies of the digastric muscle. *J Oral Rehabil* 15: 3-21.
137. Wilkinson TM. (1988) The relationship between the disk and the lateral pterygoid muscle in the human temporomandibular joint. *J Prosthet Dent*; 60: 715-724.
138. Wilkinson T, Chan EK. (1989) The anatomic relationship of the insertion of the superior lateral pterygoid muscle to the articular disc in the temporomandibular joint of human cadavers. *Aust Dent J* 34: 315-22.
139. Williams PL, Warwick R, Dyson M. (1989) *Gray's Anatomy*, 37th ed. Edinburgh: Churchill Livingstone.
140. Woelfel JB, Hickey JC, Stacy RW, Rinear L. (1960) Electromyographic analysis of jaw movements. *J Prosthet Dent* 10: 688-697.
141. Wood WW, Gelfant H, Hannam AG. (1981) Effect of occlusal reconstruction on thereproducibility of chewing movements. *J Prosthet Dent* 46: 181-184.
142. Wood WW. (1986) A functional comparison of the deep and superficial parts of the human anterior temporal muscle. *J Dent Res* 65: 924-926.
143. Wood WW. (1987) A review of masticatory muscle function. *J Prosthet Dent* 57: 222-232.
144. Wood WW, Takada K, Hannam AG. (1986) The electromyographic activity of the inferior part of the human lateral pterygoid muscle during clenching and chewing. *Arch Oral Biol* 31: 245-253.
145. Yale SH, Allison BD, Hauptfuehrer JD. (1966) An epidemiological assessment of mandibular condyle morphology. *Oral Surg Oral Med Oral Pathol* 21: 169-177.
146. Yang Y, Yatabe M, Ai M, Soneda K. (2000) The relation of canine guidance with laterotrusive movements at the incisal point and working side condyle. *J Oral Rehabil* 27: 911-917.
147. Yatabe M, Zwijnenburg A, Megens CCEJ, Naeije M. (1995) The kinematic center: a reference for condylar movements. *J Dent Res* 74: 1644-1648.

148. Zwijnenburg A, Megens CCEJ, Naeije M. (1996) Influence of choice of reference point on the condylar movement paths during mandibular movements. J Oral Rehabil 23: 832-837.

APPENDIX I



This program finds out the time when the MIPT is 1 mm, 2 mm, 3 mm and so on, away from the intercuspal position during the outgoing and return phases of each trial. Then, it matches the time parameters in the MIPT tracing files and condylar tracing files, to find the amount of condylar displacement in each axis at the same time. This program was written by the PhD candidate.

```
Option Explicit
Dim movement As Integer
Dim movem(1 To 4) As String
Dim condition As Integer
Dim cond(1 To 4) As String
Dim time(1 To 4) As Double
Dim j3d As Integer
Dim j3ds As String
Dim sn As String 'first 3 characters of subject name
Dim distance As Double
Dim trial As String
Dim inj3d(0 To 4) As Double
Dim outj3d(101 To 106, 0 To 100, 1 To 4) As Double
Dim skipped As Double
```

```
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim i101 As Integer
Dim i102 As Integer
Dim i103 As Integer
Dim intcount As Integer
Dim maxcount As Integer
```

```
Private Sub Check1_Click()
    Frame4.Enabled = True
    Check5.Enabled = True
    Check6.Enabled = True
    Check7.Enabled = True
    Check8.Enabled = True
```

```
End Sub
```

```
Private Sub Check2_Click()
    Frame4.Enabled = True
```

```

    Check5.Enabled = True
    Check6.Enabled = True
    Check7.Enabled = True
    Check8.Enabled = True

End Sub

Private Sub Check3_Click()
    Frame4.Enabled = True
    Check5.Enabled = True
    Check6.Enabled = True
    Check7.Enabled = True
    Check8.Enabled = True

End Sub

Private Sub Check4_Click()
    Frame4.Enabled = True
    Check5.Enabled = True
    Check6.Enabled = True
    Check7.Enabled = True
    Check8.Enabled = True

End Sub

Private Sub Check5_Click()
    Text1.Enabled = True

End Sub

Private Sub Check6_Click()
    Text1.Enabled = True

End Sub

Private Sub Check7_Click()
    Text1.Enabled = True

End Sub

Private Sub Check8_Click()
    Text1.Enabled = True

End Sub

Private Sub Command1_Click()
    Command1.Caption = "Processing"
    Command1.Enabled = False
    If Len(Text1.Text) <> 3 Then
        MsgBox "Please input the first three characters of the subject name"
        GoTo markend
    End If
    'comparison based on j3d
    If Option1.Value = True Then j3d = 1: j3ds = "x"
    If Option2.Value = True Then j3d = 2: j3ds = "y"
    If Option3.Value = True Then j3d = 3: j3ds = "z"
    If Option4.Value = True Then j3d = 4: j3ds = "d"

    'movements available
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: movem(movement) = "wl"
    If Check2.Value = 1 Then movement = movement + 1: movem(movement) = "pro"
    If Check3.Value = 1 Then movement = movement + 1: movem(movement) = "wlf"
    If Check4.Value = 1 Then movement = movement + 1: movem(movement) = "wlq"
    If movement = 0 Then GoTo markend

    'condition available
    condition = 0
    If Check5.Value = 1 Then condition = condition + 1: cond(condition) = "c1"
    If Check6.Value = 1 Then condition = condition + 1: cond(condition) = "o1"
    If Check7.Value = 1 Then condition = condition + 1: cond(condition) = "o2"
    If Check8.Value = 1 Then condition = condition + 1: cond(condition) = "c2"
    If condition = 0 Then GoTo markend

    'subject name and interval

```

```

sn = Text1.Text
distance = Val(Text2.Text)

'processing all movements
For i1 = 1 To movement
    'input cuttime time
    Open ("p9" & movem(i1) & ".txt") For Input As #1
        time(1) = 0
        For i101 = 2 To 4
            Input #1, time(i101)
        Next i101
    Close #1

    'open output general files
    Open (movem(i1) & "_" & j3ds & "_MS_x_out.dat") For Output As #201
    Open (movem(i1) & "_" & j3ds & "_MS_y_out.dat") For Output As #202
    Open (movem(i1) & "_" & j3ds & "_MS_z_out.dat") For Output As #203
    Open (movem(i1) & "_" & j3ds & "_MS_d_out.dat") For Output As #204
    Open (movem(i1) & "_" & j3ds & "_MA_x_out.dat") For Output As #205
    Open (movem(i1) & "_" & j3ds & "_MA_y_out.dat") For Output As #206
    Open (movem(i1) & "_" & j3ds & "_MA_z_out.dat") For Output As #207
    Open (movem(i1) & "_" & j3ds & "_MA_d_out.dat") For Output As #208
    Open (movem(i1) & "_" & j3ds & "_MP_x_out.dat") For Output As #209
    Open (movem(i1) & "_" & j3ds & "_MP_y_out.dat") For Output As #210
    Open (movem(i1) & "_" & j3ds & "_MP_z_out.dat") For Output As #211
    Open (movem(i1) & "_" & j3ds & "_MP_d_out.dat") For Output As #212
    Open (movem(i1) & "_" & j3ds & "_ML_x_out.dat") For Output As #213
    Open (movem(i1) & "_" & j3ds & "_ML_y_out.dat") For Output As #214
    Open (movem(i1) & "_" & j3ds & "_ML_z_out.dat") For Output As #215
    Open (movem(i1) & "_" & j3ds & "_ML_d_out.dat") For Output As #216
    Open (movem(i1) & "_" & j3ds & "_MM_x_out.dat") For Output As #217
    Open (movem(i1) & "_" & j3ds & "_MM_y_out.dat") For Output As #218
    Open (movem(i1) & "_" & j3ds & "_MM_z_out.dat") For Output As #219
    Open (movem(i1) & "_" & j3ds & "_MM_d_out.dat") For Output As #220
    Open (movem(i1) & "_" & j3ds & "_MS_x_back.dat") For Output As #221
    Open (movem(i1) & "_" & j3ds & "_MS_y_back.dat") For Output As #222
    Open (movem(i1) & "_" & j3ds & "_MS_z_back.dat") For Output As #223
    Open (movem(i1) & "_" & j3ds & "_MS_d_back.dat") For Output As #224
    Open (movem(i1) & "_" & j3ds & "_MA_x_back.dat") For Output As #225
    Open (movem(i1) & "_" & j3ds & "_MA_y_back.dat") For Output As #226
    Open (movem(i1) & "_" & j3ds & "_MA_z_back.dat") For Output As #227
    Open (movem(i1) & "_" & j3ds & "_MA_d_back.dat") For Output As #228
    Open (movem(i1) & "_" & j3ds & "_MP_x_back.dat") For Output As #229
    Open (movem(i1) & "_" & j3ds & "_MP_y_back.dat") For Output As #230
    Open (movem(i1) & "_" & j3ds & "_MP_z_back.dat") For Output As #231
    Open (movem(i1) & "_" & j3ds & "_MP_d_back.dat") For Output As #232
    Open (movem(i1) & "_" & j3ds & "_ML_x_back.dat") For Output As #233
    Open (movem(i1) & "_" & j3ds & "_ML_y_back.dat") For Output As #234
    Open (movem(i1) & "_" & j3ds & "_ML_z_back.dat") For Output As #235
    Open (movem(i1) & "_" & j3ds & "_ML_d_back.dat") For Output As #236
    Open (movem(i1) & "_" & j3ds & "_MM_x_back.dat") For Output As #237
    Open (movem(i1) & "_" & j3ds & "_MM_y_back.dat") For Output As #238
    Open (movem(i1) & "_" & j3ds & "_MM_z_back.dat") For Output As #239
    Open (movem(i1) & "_" & j3ds & "_MM_d_back.dat") For Output As #240

    'processing all conditions
    For i2 = 1 To condition
        For i101 = 201 To 240
            Print #i101, "movement: " & movem(i1) & " & Condition: " & cond(i2)
        Next i101
        'processing all files
        Open ("cond" & movem(i1) & cond(i2) & ".txt") For Input As #255
        Do
            'open input and output files
            Input #255, trial
            'check for abnormal tracings
            Open (sn & "i1" & trial & ".dat") For Input As #1
            Do
                Input #1, skipped, skipped, inj3d(1), inj3d(2), inj3d(3), skipped, skipped
            For i101 = 1 To 3
                If inj3d(i101) > 100 Or inj3d(i101) < -100 Then
                    For i102 = 201 To 240
                        Close #i102
                    Next i102
                End If
            Next i101
            Close #1
        Loop
    Next i2
End For

```

```

        Close #255
        MsgBox "Please remove file: " & sn & trial, , "Error of J3D file"
        GoTo markend
    End If
Next i101
Loop Until EOF(1)
Close #1
Open (sn & "i1" & trial & ".dat") For Input As #1
Open (sn & "s1" & trial & ".dat") For Input As #2
Open (sn & "a1" & trial & ".dat") For Input As #3
Open (sn & "p1" & trial & ".dat") For Input As #4
Open (sn & "l1" & trial & ".dat") For Input As #5
Open (sn & "m1" & trial & ".dat") For Input As #6
Open (sn & "s2" & trial & ".dat") For Output As #102
Open (sn & "a2" & trial & ".dat") For Output As #103
Open (sn & "p2" & trial & ".dat") For Output As #104
Open (sn & "l2" & trial & ".dat") For Output As #105
Open (sn & "m2" & trial & ".dat") For Output As #106

'Cleanup array
For i101 = 101 To 106
    For i102 = 0 To 100
        For i103 = 1 To 4
            outj3d(i101, i102, i103) = 0
        Next i103
    Next i102
Next i101
For i101 = 0 To 4
    inj3d(i101) = 0
Next i101
intcount = 0

'starting point
For i101 = 1 To 6
    Input #i101, skipped, inj3d(0), inj3d(1), inj3d(2), inj3d(3), skipped, skipped
    Input #i101, skipped, inj3d(0), inj3d(1), inj3d(2), inj3d(3), skipped, skipped
    inj3d(4) = ((inj3d(1) ^ 2) + (inj3d(2) ^ 2) + (inj3d(3) ^ 2)) ^ 0.5
    For i102 = 1 To 4
        outj3d(i101 + 100, 0, i102) = inj3d(i102)
    Next i102
Next i101

'outgoing phase determination
Do Until inj3d(0) >= time(2)
    Input #1, skipped, inj3d(0), inj3d(1), inj3d(2), inj3d(3), skipped, skipped
    For i101 = 1 To 3
        inj3d(i101) = Abs(inj3d(i101))
    Next i101
    inj3d(4) = ((inj3d(1) ^ 2) + (inj3d(2) ^ 2) + (inj3d(3) ^ 2)) ^ 0.5
    If inj3d(j3d) >= distance * (intcount + 1) Then
        intcount = intcount + 1
        For i101 = 2 To 6
            Input #i101, skipped, skipped, outj3d(i101 + 100, intcount, 1), outj3d(i101 + 100, intcount, 2),
                outj3d(i101 + 100, intcount, 3), skipped, skipped
            outj3d(i101 + 100, intcount, 4) = ((outj3d(i101 + 100, intcount, 1) ^ 2) + (outj3d(i101 + 100, intcount, 2)
                ^ 2) + (outj3d(i101 + 100, intcount, 3) ^ 2)) ^ 0.5
        Next i101
    Else
        For i101 = 2 To 6
            Input #i101, skipped, skipped, skipped, skipped, skipped, skipped, skipped
        Next i101
    End If
    If inj3d(j3d) < distance * intcount Then intcount = intcount - 1
Loop
'output outgoing data (individual trial)
For i101 = 102 To 106
    For i102 = 0 To intcount
        For i103 = 1 To 3
            Print #i101, Tab(3 + 10 * (i103 - 1)); Format(outj3d(i101, i102, i103), "0.00");
        Next i103
        Print #i101, Tab(33); (i102 + 1)
    Next i102
Next i101
'output outgoing data (general)

```

```

For i101 = 200 To 216 Step 4
  For i102 = 1 To 4
    Print # (i101 + i102), Tab(3); i2; ", ";
    For i103 = 0 To (Int(10 / distance))
      If i103 <= intcount Then
        Print # (i101 + i102), Tab(3 + 10 * (i103 + 1)); Format(outj3d(((i101 - 192) / 4 + 100), i103, i102),
          "0.00"); ", ";
      Else
        Print # (i101 + i102), Tab(3 + 10 * (i103 + 1)); "**** ";
      End If
    Next i103
    Print # (i101 + i102),
  Next i102
Next i101

'skip till return phase
Do
  Input #1, skipped, inj3d(0), inj3d(1), inj3d(2), inj3d(3), skipped, skipped
  For i101 = 2 To 6
    Input #i101, skipped, skipped, skipped, skipped, skipped, skipped, skipped
  Next i101
Loop Until inj3d(0) >= time(3)

'cleanup array
For i101 = 101 To 106
  For i102 = 0 To 100
    For i103 = 1 To 4
      outj3d(i101, i102, i103) = 0
    Next i103
  Next i102
Next i101
intcount = 0

'determination of max displace and periods (for return)
For i101 = 1 To 3
  inj3d(i101) = Abs(inj3d(i101))
Next i101
inj3d(4) = ((inj3d(1) ^ 2) + (inj3d(2) ^ 2) + (inj3d(3) ^ 2)) ^ 0.5
maxcount = Fix(inj3d(j3d) / distance)
intcount = maxcount
'return phase determination
Do
  Input #1, skipped, inj3d(0), inj3d(1), inj3d(2), inj3d(3), skipped, skipped
  For i101 = 1 To 3
    inj3d(i101) = Abs(inj3d(i101))
  Next i101
  inj3d(4) = ((inj3d(1) ^ 2) + (inj3d(2) ^ 2) + (inj3d(3) ^ 2)) ^ 0.5
  If inj3d(j3d) <= distance * intcount Then
    For i101 = 2 To 6
      Input #i101, skipped, skipped, outj3d(i101 + 100, intcount, 1), outj3d(i101 + 100, intcount, 2),
        outj3d(i101 + 100, intcount, 3), skipped, skipped
      outj3d(i101 + 100, intcount, 4) = ((outj3d(i101 + 100, intcount, 1) ^ 2) + (outj3d(i101 + 100, intcount, 2)
        ^ 2) + (outj3d(i101 + 100, intcount, 3) ^ 2)) ^ 0.5
    Next i101
    intcount = intcount - 1
  Else
    For i101 = 2 To 6
      Input #i101, skipped, skipped, skipped, skipped, skipped, skipped, skipped
    Next i101
  End If
  If inj3d(j3d) > distance * (intcount + 1) Then intcount = intcount + 1
Loop Until inj3d(0) > (time(4) - 0.2)
'mm0
If intcount = 0 Then
  For i101 = 2 To 6
    Input #i101, skipped, skipped, outj3d(i101 + 100, intcount, 1), outj3d(i101 + 100, intcount, 2),
      outj3d(i101 + 100, intcount, 3), skipped, skipped
    outj3d(i101 + 100, intcount, 4) = ((outj3d(i101 + 100, intcount, 1) ^ 2) + (outj3d(i101 + 100, intcount, 2)
      ^ 2) + (outj3d(i101 + 100, intcount, 3) ^ 2)) ^ 0.5
  Next i101
  intcount = -1
End If
intcount = intcount + 1

```

```

'output return data (individual trial)
For i101 = 102 To 106
  For i102 = maxcount To intcount Step -1
    For i103 = 1 To 3
      Print #i101, Tab(3 + 10 * (i103 - 1)); Format(outj3d(i101, i102, i103), "0.00");
    Next i103
    Print #i101, Tab(33); (i102 + 1001)
  Next i102
Next i101

'output return data (general)
For i101 = 220 To 236 Step 4
  For i102 = 1 To 4
    Print #(i101 + i102), Tab(3); i2; ", ";
    For i103 = 0 To (Int(10 / distance))
      If i103 >= intcount And i103 <= maxcount Then
        Print #(i101 + i102), Tab(3 + 10 * (i103 + 1)); Format(outj3d(((i101 - 212) / 4 + 100), i103, i102),
          "0.00"); ", ";
      Else
        Print #(i101 + i102), Tab(3 + 10 * (i103 + 1)); "**** ";
      End If
    Next i103
    Print #(i101 + i102),
  Next i102
Next i101

'closing files of each trial
For i101 = 1 To 6
  Close #i101
Next
For i101 = 102 To 106
  Close #i101
Next i101
Loop Until EOF(255)
Close #255
Next i2

For i101 = 201 To 240
  Close #i101
Next i101

Next i1

markend:

Command1.Caption = "Restart"
Beep
MsgBox "Processing complete!"
End Sub

Private Sub Dir1_Change()
  ChDir (Dir1.Path)
  Label2.Caption = CurDir$(Drive1.Drive)
  File1.Path = CurDir$(Drive1.Drive)
  Frame1.Enabled = True
  Option1.Enabled = True
  Option2.Enabled = True
  Option3.Enabled = True
  Option4.Enabled = True
End Sub

Private Sub Drive1_Change()
  ChDrive (Drive1.Drive)
  Dir1.Path = CurDir$(Drive1.Drive)

End Sub

Private Sub Option1_Click()
  Frame2.Enabled = True
  Frame3.Enabled = True
  Check1.Enabled = True
  Check2.Enabled = True
  Check3.Enabled = True
  Check4.Enabled = True

```

End Sub

Private Sub Option2_Click()

Frame2.Enabled = True

Frame3.Enabled = True

Check1.Enabled = True

Check2.Enabled = True

Check3.Enabled = True

Check4.Enabled = True

End Sub

Private Sub Option3_Click()

Frame2.Enabled = True

Frame3.Enabled = True

Check1.Enabled = True

Check2.Enabled = True

Check3.Enabled = True

Check4.Enabled = True

End Sub

Private Sub Option4_Click()

Frame2.Enabled = True

Frame3.Enabled = True

Check1.Enabled = True

Check2.Enabled = True

Check3.Enabled = True

Check4.Enabled = True

End Sub

Private Sub Text1_Change()

Command1.Enabled = True

End Sub

APPENDIX II

This formula calculates the rotation angles about the three axes (i.e. X, Y and Z) during three-dimension rotation of the mandible. These formulae were provided by A/Prof. Chris Durrant.

Rotation Analysis

Suppose we measure the positions of n condylar points (5 in the example) each time. Let the initial positions be (X_i, Y_i, Z_i) for $i = 1, n$. These are in the file position.dat.

The JAWS3D output then gives the displacements of the points from these positions at chosen intervals subsequently. Let these be $(\delta X_i, \delta Y_i, \delta Z_i)$. The new positions are therefore (X'_i, Y'_i, Z'_i) for $i = 1, n$, where

$$X'_i = X_i + \delta X_i, \quad Y'_i = Y_i + \delta Y_i, \quad Z'_i = Z_i + \delta Z_i.$$

We want the rotations involved in going from (X_i, Y_i, Z_i) to (X'_i, Y'_i, Z'_i) . First remove the translation in the X direction by forming the mean coordinates $\bar{X} = (1/n) \sum_1^n X_i$, $\bar{X}' = (1/n) \sum_1^n X'_i$ and subtracting to obtain the relative coordinates

$$x_i = X_i - \bar{X}, \quad x'_i = X'_i - \bar{X}'.$$

The translations in Y and Z are removed in similar fashion. Then the transformation from (x_i, y_i, z_i) to (x'_i, y'_i, z'_i) is a rotation.

If an object (i.e., the axes fixed in the object) is rotated an angle A about the X -axis, then an angle B about the original Y -axis and, finally, an angle C about the original Z -axis, the coordinates (x, y, z) of a point measured before the rotation become (x', y', z') after the rotation where

$$\begin{aligned} x' &= (\cos B \cos C)x + (\sin A \sin B \cos C - \cos A \sin C)y + (\cos A \sin B \cos C + \sin A \sin C)z \\ y' &= (\cos B \sin C)x + (\sin A \sin B \sin C + \cos A \cos C)y + (\cos A \sin B \sin C - \sin A \cos C)z \\ z' &= -(\sin B)x + (\sin A \cos B)y + (\cos A \cos B)z. \end{aligned}$$

It can be seen that this transformation is not symmetric in A , B and C so that the relations are different if the rotations are made in a different order. However, if the angles are small, we may approximate

$$\sin A \approx A, \quad \cos A \approx 1,$$

where A is measured in radians. The error in $\sin A$ is of the order of $A^3/6$ and the error in $\cos A$ is of the order of $A^2/2$. In this case

$$\begin{aligned} x' &= x - Cy + Bz \\ y' &= Cx + y - Az \\ z' &= -Bx + Ay + z. \end{aligned}$$

This form is symmetric so the result is independent of the order of rotation. The angles are then found by solving the $3n$ equations

$$\begin{aligned} x'_i &= x_i - Cy_i + Bz_i \\ y'_i &= Cx_i + y_i - Az_i \\ z'_i &= -Bx_i + Ay_i + z_i, \end{aligned}$$

for $i = 1, n$.

If there is no measurement error, this approximation yields the true angles of rotation correct to 1% for angles of 1° , 2.5% for angles of 5° and 10% for angles of 10° .

In the presence of measurement errors, we need to estimate A , B and C . If we write the set of $3n$ equations in the form

$$\begin{aligned}
 x'_1 - x_1 &= 0A + z_1B - y_1C \\
 &\vdots \\
 x'_n - x_n &= 0A + z_nB - y_nC \\
 y'_1 - y_1 &= -z_1A + 0B + x_1C \\
 &\vdots \\
 y'_n - y_n &= -z_nA + 0B + x_nC \\
 z'_1 - z_1 &= y_1A - x_1B + 0z_1 \\
 &\vdots \\
 z'_n - z_n &= y_nA - x_nB + 0z_n,
 \end{aligned}$$

we see that we can find the angles by performing a linear least-squares regression on

$$y = Ax_1 + Bx_2 + Cx_3,$$

where y is the n -dimensional vector

$$y = \begin{pmatrix} x'_1 - x_1 \\ \vdots \\ x'_n - x_n \\ y'_1 - y_1 \\ \vdots \\ y'_n - y_n \\ z'_1 - z_1 \\ \vdots \\ z'_n - z_n \end{pmatrix},$$

and the array x is

$$x = \begin{pmatrix} 0 & z_1 & -y_1 \\ \vdots & \vdots & \vdots \\ 0 & z_n & -y_n \\ -z_1 & 0 & x_1 \\ \vdots & \vdots & \vdots \\ -z_n & 0 & x_n \\ y_1 & -x_1 & 0 \\ \vdots & \vdots & \vdots \\ y_n & -x_n & 0 \end{pmatrix}.$$

This program calculates the rotation angles about the three axes (i.e. X, Y and Z) during three-dimension rotation of the mandible. The MicroSoft® Excel template was provided by A/Prof. Chris Durrant, and the macro was written by the PhD candidate.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288	1289	1290	1291	1292	1293	1294	1295	1296	1297	1298	1299	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314	1315	1316	1317	1318	1319	1320	1321	1322	1323	1324	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338	1339	1340	1341	1342	1343	1344	1345	1346	1347	1348	1349	1350	1351	1352	1353	1354	1355	1356	1357	1358	1359	1360	1361	1362	1363	1364	1365	1366	1367	1368	1369	1370	1371	1372	1373	1374	1375	1376	1377	1378	1379	1380	1381	1382	1383	1384	1385	1386	1387	1388	1389	1390	1391	1392	1393	1394	1395	1396	1397	1398	1399	1400	1401	1402	1403	1404	1405	1406	1407	1408	1409	1410	1411	1412	1413	1414	1415	1416	1417	1418	1419	1420	1421	1422	1423	1424	1425	1426	1427	1428	1429	1430	1431	1432	1433	1434	1435	1436	1437	1438	1439	1440	1441	1442	1443	1444	1445	1446	1447	1448	1449	1450	1451	1452	1453	1454	1455	1456	1457	1458	1459	1460	1461	1462	1463	1464	1465	1466	1467	1468	1469	1470	1471	1472	1473	1474	1475	1476	1477	1478	1479	1480	1481	1482	1483	1484	1485
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

```

For i101 = 201 To 206
    Print #i101,
    Print #i101,
    Print #i101, "Movement: " & Movem & " Condition: " & cond(i1)
Next i101
'processing all files
Open (ford & "cond" & Movem & cond(i1) & ".txt") For Input As #255
Do
    Input #255, trial
    Open (ford & sn & "s2" & trial & ".dat") For Input As #1
    Open (ford & sn & "a2" & trial & ".dat") For Input As #2
    Open (ford & sn & "p2" & trial & ".dat") For Input As #3
    Open (ford & sn & "m2" & trial & ".dat") For Input As #4
    Open (ford & sn & "l2" & trial & ".dat") For Input As #5
    intcount = 0
    maxcount = 0
    For i101 = 0 To 100
        For i102 = 1 To 3
            outj3d(1, i101, i102) = -9999
            outj3d(2, i101, i102) = -9999
        Next i102
    Next i101
    Do 'processing all data within the trial
        For i101 = 1 To 5 'input displacement data
            Input #i101, inj3d(1), inj3d(2), inj3d(3), dist
            For i102 = 2 To 4
                Cells(i101 + 15, i102).Value = inj3d(i102 - 1)
            Next i102
        Next i101

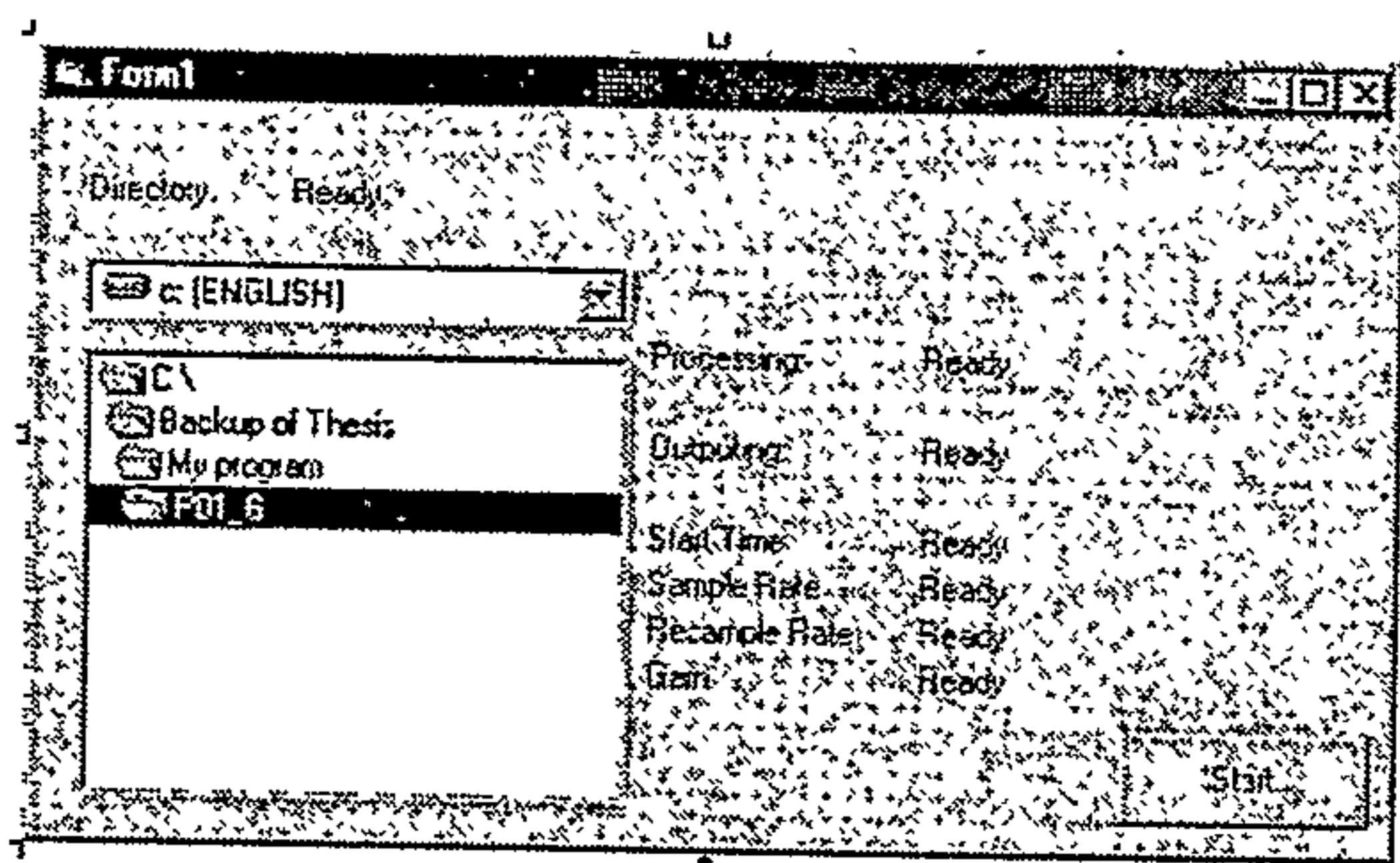
        If dist < 100 Then 'output data: outgoing phase
            outj3d(1, dist, 1) = Cells(22, 16).Value
            outj3d(1, dist, 2) = Cells(22, 17).Value
            outj3d(1, dist, 3) = Cells(22, 18).Value
        End If
        If dist > 100 Then 'output data: return phase
            outj3d(2, (dist - 1000), 1) = Cells(22, 16).Value
            outj3d(2, (dist - 1000), 2) = Cells(22, 17).Value
            outj3d(2, (dist - 1000), 3) = Cells(22, 18).Value
        End If
    Loop Until EOF(1)
    'output to files
    For i101 = 201 To 206 'conditions
        Print #i101, i1;
        Print #(i101 + 10), i1;
    Next i101
    For i101 = 201 To 203 'output outgoing
        For i102 = 1 To outmax
            If outj3d(1, i102, i101 - 200) > -9998 Then
                Print #i101, ","; Tab(10 * i102); Format(outj3d(1, i102, i101 - 200), "0.00000");
                Print #(i101 + 10), ","; Tab(10 * i102); Format(outj3d(1, i102, i101 - 200), "0.00000");
            Else
                Print #i101, ","; Tab(10 * i102); "****";
                Print #(i101 + 10), ","; Tab(10 * i102); "****";
            End If
        Next i102
    Next i101
    For i101 = 204 To 206 'output return
        For i102 = 1 To outmax
            If outj3d(2, i102, i101 - 203) > -9998 Then
                Print #i101, ","; Tab(10 * i102); Format(outj3d(2, i102, i101 - 203), "0.00000");
                Print #(i101 + 10), ","; Tab(10 * i102); Format(outj3d(2, i102, i101 - 203), "0.00000");
            Else
                Print #i101, ","; Tab(10 * i102); "****";
                Print #(i101 + 10), ","; Tab(10 * i102); "****";
            End If
        Next i102
    Next i101
    For i101 = 201 To 206
        Print #i101,
        Print #(i101 + 10),
    Next i101
    For i101 = 1 To 5
        Close #i101
    Next i101

```

```
    Loop Until EOF(255)
    Close #255
Next il
mark_end:
For i101 = 201 To 206
    Close #i101
    Close #(i101 + 10)
Next i101

Cells(1, 10) = "Finish"
End Sub
```

APPENDIX III



This program processes the output EMG files of the CED system. The EMG activity of each trial was re-sampled to ~2,500 samples/s by deleting three of every four data samples. Then, the time parameter was added for later process. This program was written by the PhD candidate.

Option Explicit

```
'setup of system variable
Dim infileindex As String
Dim infilename As String
Dim outfileindex As String
Dim outfileindex(7 To 12) As String
Dim outfilename As Integer
Dim gain(7 To 12) As Integer
```

```
Dim counter1 As Integer
Dim counter2 As Integer
Dim i As Integer
Dim outline As Integer
```

```
Dim dirsetup As String
```

```
'setup of input variable
```

```
Dim inputstring As String
Dim time As Double
Dim increment(7 To 12) As Double
Dim cuttime As Double
Dim emg As Double
```

```
Private Sub Command1_Click()
```

```
Open (dirsetup & "parameter.txt") For Input As #1
Do Until EOF(1)
```

```
Input #1, infileindex, gain(7), gain(8), gain(9), gain(10), gain(11), gain(12), cuttime
outfileindex = dirsetup & "uf" & infileindex
infileindex = dirsetup & infileindex
```

```
infilename = infileindex & ".txt"
outfileindex(7) = outfileindex & "_7.txt"
outfileindex(8) = outfileindex & "_8.txt"
outfileindex(9) = outfileindex & "_9.txt"
outfileindex(10) = outfileindex & "_10.txt"
outfileindex(11) = outfileindex & "_11.txt"
outfileindex(12) = outfileindex & "_12.txt"
```

```
Open infilename For Input As #2
```

```
Label2.Caption = infilename
```

```
For counter1 = 1 To 16
Line Input #2, inputstring
Next
```

```
For counter1 = 7 To 12
```

```

Open outfilename(counter1) For Output As #3

  For counter2 = 1 To 6
    Line Input #2, inputstring
  Next

  Input #2, inputstring, time, increment(counter1)
  If increment(counter1) <= 0.00014 Then
    cutline = 3
  Else:
    cutline = 1
  End If

  Label4.Caption = outfilename(counter1)
  Label6.Caption = Format(time, "0.000000")
  Label8.Caption = Format(1 / increment(counter1), "0.000000")
  Label10.Caption = Format(1 / ((cutline + 1) * increment(counter1)), "0.000000")
  Label12.Caption = Format(gain(counter1), "#0")

  Do
    Input #2, emg
    emg = emg * 10 / gain(counter1)
    Print #3, Format(time, "#0.000000"), Format(emg, "#0.0000000")
    For i = 1 To cutline
      Input #2, emg
    Next
    time = time + increment(counter1) * (cutline + 1)
  Loop Until time >= cuttime

  Input #2, emg
  emg = emg * 10 / gain(counter1)
  Print #3, Format(time, "#0.000000"), Format(emg, "#0.0000000")

  If counter1 = 12 Then GoTo mark1

  Do
    Input #2, inputstring
  Loop Until (inputstring = "")

mark1:

  Close 3
Next

Close 2

Loop 'processing parameter.txt as #1

Close 1

Label2.Caption = "End"
Label4.Caption = "End"
Label6.Caption = "End"
Label8.Caption = "End"
Label10.Caption = "End"
Label12.Caption = "End"
Command1.Caption = "Restart"
End Sub

Private Sub Dir1_Change()

  dirsetup = Dir1.Path & "\
  Label14.Caption = dirsetup

End Sub

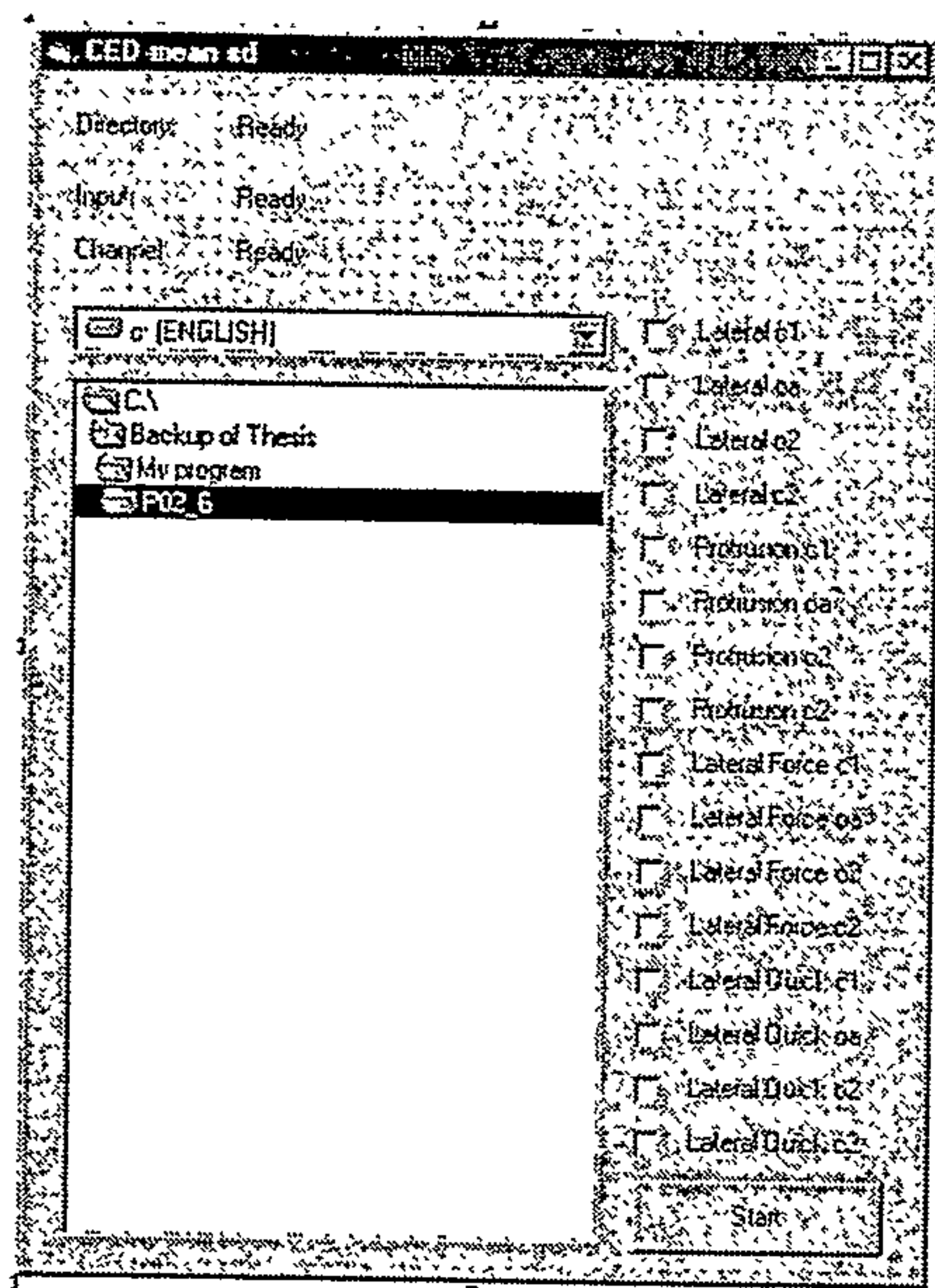
Private Sub Drive1_Change()

  Dir1.Path = Drive1.Drive

End Sub

```

APPENDIX IV



This program calculates the mean and standard deviation of EMG activity of 10 trials under the same occlusal condition. An additional program, of which the source code is not shown below, generates the command file for plotting the average EMG activity. These programs were written by the PhD candidate.

```
Option Explicit
Dim stepindex As Integer
Dim counterfilegeneral As Integer
Dim counterfilelocal As Integer
Dim channel As Integer
Dim i1 As Integer
Dim i2 As Integer
Dim inputtime As Double
Dim inputemg(1 To 20) As Double
Dim emgmean As Double
Dim emgsd As Double
Dim dirsetup As String
Dim infileindex(1 To 20) As String
Dim infilename(1 To 20) As String
Dim indexfile(1 To 16) As String
```

```
Private Sub Command1_Click()
i2 = 0
If Check1.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlc1"
If Check2.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wloa"
If Check3.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlc2"
If Check4.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "proc1"
If Check5.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "prooa"
If Check6.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "proc2"
If Check7.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlfc1"
If Check8.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlfoa"
If Check9.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlfc2"
If Check10.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlo2"
If Check11.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "proo2"
If Check12.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlfo2"
If Check13.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlqc1"
If Check14.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlqoa"
If Check15.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlqo2"
If Check16.Value = 1 Then i2 = i2 + 1: indexfile(i2) = dirsetup & "wlqc2"
If i2 = 0 Then GoTo End1
For stepindex = 1 To i2
Label3.Caption = indexfile(stepindex) & ".txt"

'input fileindex and count total file
counterfilegeneral = 0
Open (indexfile(stepindex) & ".txt") For Input As #1
```

```

Do
    counterfilegeneral = counterfilegeneral + 1
    Input #1, infileindex(counterfilegeneral)
    Loop Until EOF(1)
Close 1

'processing 6 channel
For channel = 7 To 12
    Label4.Caption = Format(channel, "00")
    'generate input filename
    For i1 = 1 To counterfilegeneral
        infilename(i1) = dirsetup & "f" & infileindex(i1) & "_" & Format(channel, "##") & ".txt"
    Next

    'open input and output file
    For counterfilelocal = 1 To counterfilegeneral
        Open infilename(counterfilelocal) For Input As #counterfilelocal
    Next
    Open (indexfile(stepindex) & "_" & Format(channel, "##") & "_all.txt") For Output As #255

    'Data input and output
    Do
        'read and processing emgmean
        emgmean = 0
        For counterfilelocal = 1 To counterfilegeneral
            Input #counterfilelocal, inputtime, inputemg(counterfilelocal)
            emgmean = emgmean + inputemg(counterfilelocal)
        Next
        emgmean = emgmean / counterfilegeneral

        'processing emgsd
        emgsd = 0
        For counterfilelocal = 1 To counterfilegeneral
            emgsd = emgsd + (inputemg(counterfilelocal) - emgmean) ^ 2
        Next
        emgsd = (emgsd / (counterfilegeneral - 1)) ^ 0.5

        'write
        Print #255, Format(inputtime, "#0.0000000"),
            'For counterfilelocal = 1 To counterfilegeneral
            'Print #255, Format(inputemg(counterfilelocal), "#0.0000000"),
            'Next
        Print #255, Format(emgmean, "#0.0000000"), Format(emgsd, "#0.0000000")

    Loop Until EOF(1)

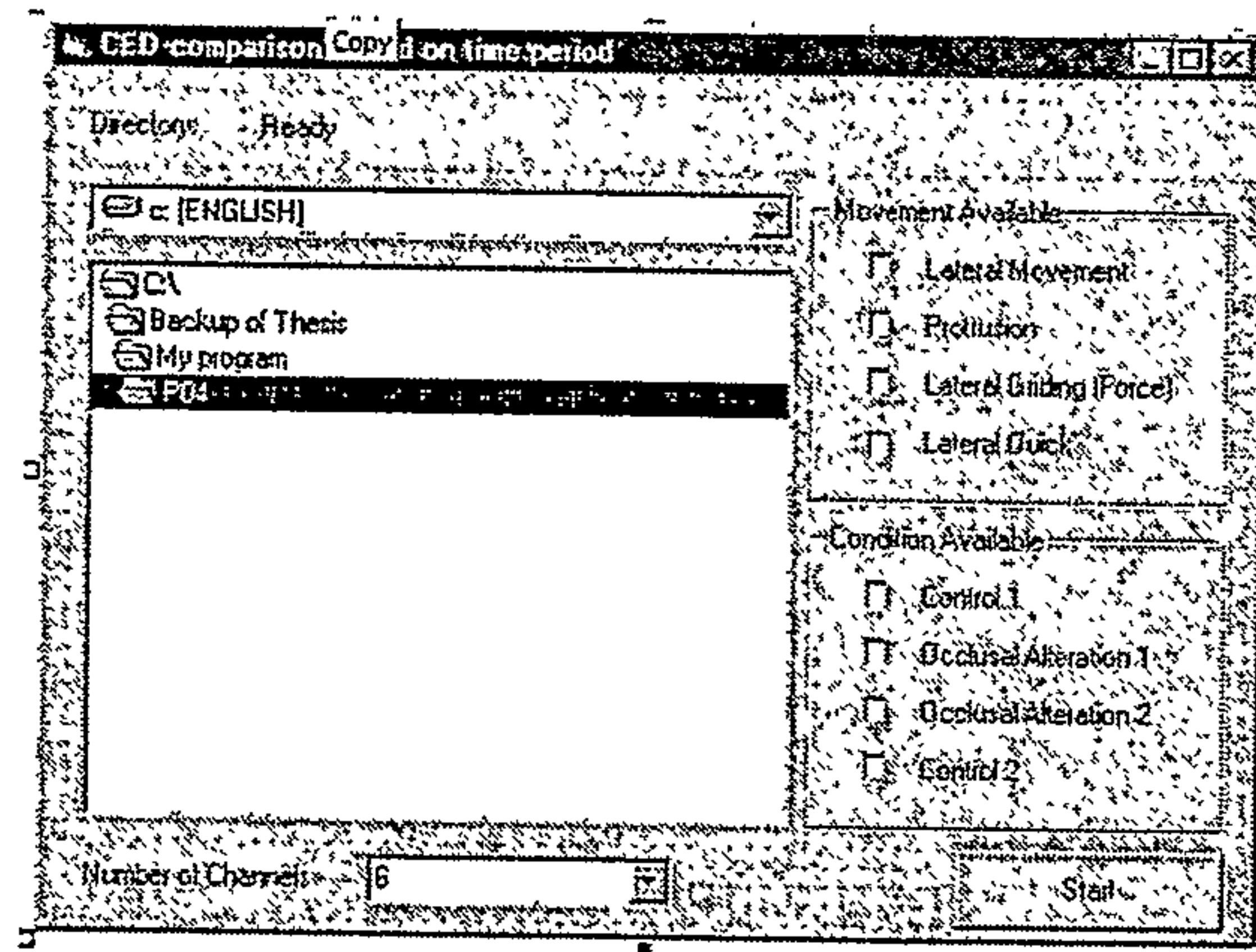
    'close input and output file
    For counterfilelocal = 1 To counterfilegeneral
        Close counterfilelocal
    Next
    Close 255
Next
Next
End1:
Label3.Caption = "End"
Label4.Caption = "End"
Command1.Caption = "Restart"
Command1.Enabled = False
End Sub

Private Sub Dir1_Change()
    dirsetup = Dir1.Path & "\"
    Label15.Caption = dirsetup
    Command1.Enabled = True
End Sub

Private Sub Drive1_Change()
    Dir1.Path = Drive1.Drive
End Sub

```

APPENDIX V



This program calculates the average area (total area/duration) under the EMG curve based at each defined time period. An additional program, of which the source code is not shown below, reformats the output files in a format that can be imported in SPSS for speeding the data processing. These programs were written by the PhD candidate.

```
Option Explicit
Dim dirsetup As String
Dim infile(1 To 4) As String
Dim condition(1 To 4) As String
Dim infilename As String
Dim channelnumber As Integer
Dim cond As Integer
Dim movement As Integer
Dim inputtime As Double
Dim inputemg As Double
Dim emgmean As Double

'setup counter
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim i10 As Integer
Dim period As Integer
Dim countpoint As Integer
Dim timep(0 To 20) As Double

Private Sub Combo1_Change()
    If (Val(Combo1.Text) < 1 Or Val(Combo1.Text) > 8) Then Combo1.Text = 6
End Sub

Private Sub Command1_Click()

    'setup movement
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: infile(movement) = dirsetup & "w1"
    If Check2.Value = 1 Then movement = movement + 1: infile(movement) = dirsetup & "pro"
    If Check3.Value = 1 Then movement = movement + 1: infile(movement) = dirsetup & "wlf"
    If Check8.Value = 1 Then movement = movement + 1: infile(movement) = dirsetup & "wlq"

    If movement = 0 Then GoTo Markend

    'setup condition
    cond = 0
    If Check4.Value = 1 Then cond = cond + 1: condition(cond) = "c1"
    If Check5.Value = 1 Then cond = cond + 1: condition(cond) = "oa"
    If Check6.Value = 1 Then cond = cond + 1: condition(cond) = "o2"
    If Check7.Value = 1 Then cond = cond + 1: condition(cond) = "c2"
    If cond = 0 Then GoTo Markend

    'setup channel number
    channelnumber = CInt(Val(Combo1.Text))
```

```

'processing all channels
For i1 = (channelnumber + 1) To (channelnumber * 2)
    'processing movements
    For i2 = 1 To movement
        'input period timing
        Open (infile(i2) & "time.txt") For Input As #1
        Input #1, period 'total periods
        timep(0) = 0
        For i3 = 1 To period
            Input #1, timep(i3)
        Next i3
        Close #1

        'open spss.txt file for output as #255
        Open (infile(i2) & "spss_" & Format(i1, "##") & ".txt") For Output As #255

        'processing condition
        For i10 = 1 To cond
            Open (infile(i2) & condition(i10) & ".txt") For Input As #1
            Do Until EOF(1)
                'get filename for opening and processing
                Input #1, infilename
                Open (dirsetup & "f" & infilename & "_" & Format(i1, "##") & ".txt") For Input As #2
                'for first column
                Print #255, i10,

                inputemg = 0
                countpoint = -1

                'Processing data in different period
                For i3 = 1 To period
                    emgmean = 0
                    Do
                        countpoint = countpoint + 1
                        emgmean = emgmean + inputemg
                        Input #2, inputtime, inputemg
                    Loop Until (inputtime > timep(i3) Or EOF(2))
                    emgmean = emgmean / countpoint
                    Print #255, Format(emgmean, "#.0000000"),
                    countpoint = 0
                Next i3

                'change line in #255
                Print #255,
            Close #2
        Loop
        Close #1
    Next i10

    'close spss.txt file #255
    Close #255
Next i2
Next i1

Markend:
    Command1.Enabled = False
    Command1.Caption = "Restart"
End Sub

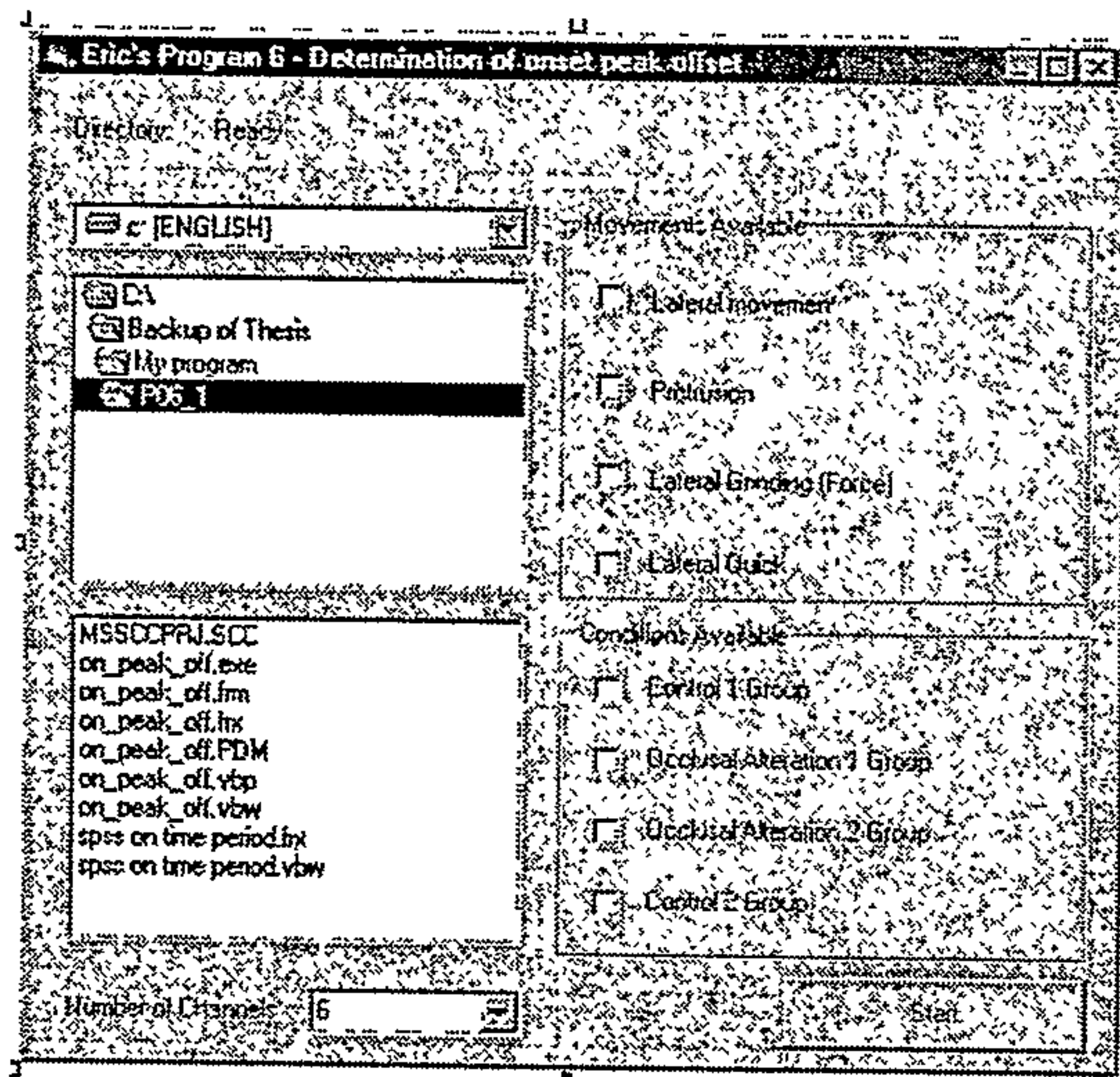
Private Sub Dir1_Change()
    dirsetup = Dir1.Path & "\
    Label2.Caption = dirsetup
    Command1.Enabled = True
End Sub

Private Sub Drive1_Change()
    Dir1.Path = Drive1.Drive
End Sub

```

APPENDIX VI

The first program calculates the onset, peak and offset of MIPT displacement and EMG activity of each trial. The second program compares the onset (and peak and offset) times between the MIPT movements and the EMG activity of the selected muscle. An additional program, of which the source code is not shown below, reformats the output files in formats that can be imported in SPSS and MicroSoft® Word for speeding the data processing. These programs were written by the PhD candidate.



```
Option Explicit
Dim movement As Integer
Dim movem(1 To 4) As String
Dim condition As Integer
Dim cond(1 To 4) As String
Dim channel As Integer
Dim j3df As String
Dim cedf As String
'dim j3d data
Dim j3d(0 To 68, 1 To 5) As Double
Dim i255 As Integer
Dim i254 As Double
Dim i253 As Integer
Dim meanj3d(2 To 5) As Double
Dim sdj3d(2 To 5) As Double
Dim ontime(2 To 5) As Double
Dim maxon(2 To 5) As Double
Dim peaktime(2 To 5) As Double
Dim maxpeak(2 To 5) As Double
Dim maxoff(2 To 5) As Double
Dim indicator(2 To 5) As Integer
Dim peakmove(2 To 5) As Double
'dim ced data
Dim cedtime As Double
Dim cedemg As Double
Dim emg(1 To 3000) As Double
Dim cedmean As Double
Dim cedsd As Double
Dim cedon(1 To 2) As Double
Dim cedpeak(1 To 2) As Double
Dim cedoff(1 To 2) As Double
Dim maxced As Double
Dim cedin As Integer
'dim counter
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim i4 As Integer
'dim local counter
Dim i101 As Integer
```

```

Dim i102 As Integer

Private Sub Combo1_Change()
If (Val(Combo1.Text) < 1 Or Val(Combo1.Text) > 8) Then Combo1.Text = 6

End Sub
Private Sub Command1_Click()
    Command1.Enabled = False

    'movement available
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: movem(movement) = "w1"
    If Check2.Value = 1 Then movement = movement + 1: movem(movement) = "pro"
    If Check3.Value = 1 Then movement = movement + 1: movem(movement) = "wlf"
    If Check8.Value = 1 Then movement = movement + 1: movem(movement) = "wlq"
    If movement = 0 Then GoTo Markend

    'condition available
    condition = 0
    If Check4.Value = 1 Then condition = condition + 1: cond(condition) = "c1"
    If Check5.Value = 1 Then condition = condition + 1: cond(condition) = "oa"
    If Check6.Value = 1 Then condition = condition + 1: cond(condition) = "o2"
    If Check7.Value = 1 Then condition = condition + 1: cond(condition) = "c2"
    If condition = 0 Then GoTo Markend

    'number of channels
    channel = CInt(Val(Combo1.Text))

    'Processing all movements
    For i1 = 1 To movement
        'processng all conditions
        For i2 = 1 To condition
            'input overall processing file name and output file name
            Open ("jc" & movem(i1) & cond(i2) & ".txt") For Input As #1
            Open ("jc" & movem(i1) & cond(i2) & "_opo.txt") For Output As #255
            Open ("rjc" & movem(i1) & cond(i2) & ".txt") For Output As #254
            'processing each trial
            Do Until EOF(1)
                Input #1, j3df, cedf
                'print processing filename of j3d and ced
                Print #255, "Filename: "; j3df; " and "; cedf
                Print #255,

            'processing j3d data
            'get mean and sd
            Open (j3df & ".dat") For Input As #2
            'clean up meanj3d() and sdj3d()
            For i101 = 2 To 5
                meanj3d(i101) = 0
                sdj3d(i101) = 0
            Next i101

            'input data of first second and calculate D and mean
            For i101 = 0 To 68
                Input #2, i255, j3d(i101, 1), j3d(i101, 2), j3d(i101, 3), j3d(i101, 4), i254, i253
                j3d(i101, 5) = (j3d(i101, 2) ^ 2 + j3d(i101, 3) ^ 2 + j3d(i101, 4) ^ 2) ^ 0.5
                meanj3d(2) = meanj3d(2) + j3d(i101, 2)
                meanj3d(3) = meanj3d(3) + j3d(i101, 3)
                meanj3d(4) = meanj3d(4) + j3d(i101, 4)
                meanj3d(5) = meanj3d(5) + j3d(i101, 5)
            Next i101
            For i101 = 2 To 5
                meanj3d(i101) = meanj3d(i101) / 68
            Next i101

            'calculate sd
            For i101 = 2 To 5
                For i102 = 1 To 68
                    sdj3d(i101) = sdj3d(i101) + (j3d(i102, i101) - meanj3d(i101)) ^ 2
                Next i102
                sdj3d(i101) = (sdj3d(i101) / 67) ^ 0.5
            Next i101
            Close #2

            'determination the time of onset peak and offset

```

```

For i101 = 2 To 5
    indicator(i101) = 2
    ontime(i101) = 0
    maxon(i101) = 0
    maxoff(i101) = 0
    peaktime(i101) = 0
    maxpeak(i101) = 0
    peakmove(i101) = meanj3d(i101)
Next i101

Open (j3df & ".dat") For Input As #2
Do Until EOF(2)
    Input #2, i255, j3d(0, 1), j3d(0, 2), j3d(0, 3), j3d(0, 4), i254, i253
    j3d(0, 5) = (j3d(0, 2) ^ 2 + j3d(0, 3) ^ 2 + j3d(0, 4) ^ 2) ^ 0.5
    If j3d(0, 5) > 50 Then
        Close 1
        Close 2
        Close 255
        MsgBox "Please remove file: " & j3df & ".dat", , "Error of J3D file"
        GoTo Markend
    End If

    For i101 = 2 To 5
        'more
        'onset
        If (indicator(i101) = 2 And j3d(0, i101) > (meanj3d(i101) + 2 * sdj3d(i101))) Then
            indicator(i101) = 3
            ontime(i101) = j3d(0, 1)
        End If
        'peak
        If (indicator(i101) = 3 And j3d(0, i101) > peakmove(i101)) Then
            peakmove(i101) = j3d(0, i101)
            peaktime(i101) = j3d(0, 1)
        End If
        'offset
        If (indicator(i101) = 3 And j3d(0, i101) < (meanj3d(i101) + 2 * sdj3d(i101))) Then
            If j3d(0, 1) - ontime(i101) > maxoff(i101) - maxon(i101) Then
                indicator(i101) = 2
                maxon(i101) = ontime(i101)
                maxpeak(i101) = peaktime(i101)
                maxoff(i101) = j3d(0, 1)
                peakmove(i101) = meanj3d(i101)
                ontime(i101) = 0
                peaktime(i101) = 0
            Else
                indicator(i101) = 2
                peakmove(i101) = meanj3d(i101)
                ontime(i101) = 0
                peaktime(i101) = 0
            End If
        End If
        'less
        'onset
        If (indicator(i101) = 2 And j3d(0, i101) < (meanj3d(i101) - 2 * sdj3d(i101))) Then
            indicator(i101) = 1
            ontime(i101) = j3d(0, 1)
        End If
        'peak
        If (indicator(i101) = 1 And j3d(0, i101) < peakmove(i101)) Then
            peakmove(i101) = j3d(0, i101)
            peaktime(i101) = j3d(0, 1)
        End If
        'offset
        If (indicator(i101) = 1 And j3d(0, i101) > (meanj3d(i101) - 2 * sdj3d(i101))) Then
            If j3d(0, 1) - ontime(i101) > maxoff(i101) - maxon(i101) Then
                indicator(i101) = 2
                maxon(i101) = ontime(i101)
                maxpeak(i101) = peaktime(i101)
                maxoff(i101) = j3d(0, 1)
                peakmove(i101) = meanj3d(i101)
                ontime(i101) = 0
                peaktime(i101) = 0
            Else
                indicator(i101) = 2
                peakmove(i101) = meanj3d(i101)
            End If
        End If
    Next i101
Loop
Markend

```

```

        ontime(i101) = 0
        peakttime(i101) = 0
    End If
End If
Next i101
Loop
Close 2
For i101 = 2 To 5
    If indicator(i101) <> 2 And j3d(0, 1) - ontime(i101) > maxoff(i101) - maxon(i101) Then
        maxon(i101) = ontime(i101)
        maxpeak(i101) = peakttime(i101)
        maxoff(i101) = 0
    End If
Next i101

'print j3d on peak off
Print #255, "List"; Tab(10); "Onset"; Tab(30); "Peak"; Tab(50); "Offset"
Print #255, "J3D_X,"; Tab(10); Format(maxon(2), "##.000"); ","; Tab(30); Format(maxpeak(2), "##.000");
    ","; Tab(50); Format(maxoff(2), "##.000")
Print #255, "J3D_Y,"; Tab(10); Format(maxon(3), "##.000"); ","; Tab(30); Format(maxpeak(3), "##.000");
    ","; Tab(50); Format(maxoff(3), "##.000")
Print #255, "J3D_Z,"; Tab(10); Format(maxon(4), "##.000"); ","; Tab(30); Format(maxpeak(4), "##.000");
    ","; Tab(50); Format(maxoff(4), "##.000")
Print #255, "J3D_D,"; Tab(10); Format(maxon(5), "##.000"); ","; Tab(30); Format(maxpeak(5), "##.000");
    ","; Tab(50); Format(maxoff(5), "##.000")
'rtc preparation
Print #254, j3df; ","; j3d(0, 1)

'processing ced data all channel
For i3 = (channel + 1) To (2 * channel)
    'open ced channel for input mean and sd
    Open ("f" & cedf & "_" & Format(i3, "##") & ".txt") For Input As #2
        i4 = 0
        cedmean = 0
        cedsd = 0
        'input and mean
        Do
            i4 = i4 + 1
            Input #2, cedtime, emg(i4)
            cedmean = cedmean + emg(i4)
        Loop Until cedtime >= 1
        cedmean = cedmean / i4
        'calculate sd
        For i101 = 1 To i4
            cedsd = cedsd + (emg(i101) - cedmean) ^ 2
        Next i101
        cedsd = cedsd / (i4 - 1)
        cedsd = cedsd ^ 0.5
    Close #2

    'cleanup
    For i101 = 1 To 2
        cedon(i101) = 0
        cedpeak(i101) = 0
        cedoff(i101) = 0
    Next i101
    maxced = cedmean
    cedin = 1

    'open ced channel again for on peak off
    Open ("f" & cedf & "_" & Format(i3, "##") & ".txt") For Input As #2
        Do
            Input #2, cedtime, cedemg

            'more
            'onset
            If (cedin = 1 And cedemg > cedmean + (2 * cedsd)) Then
                cedin = 2
                cedon(1) = cedtime
            End If
            'peak
            If (cedin = 2 And cedemg > maxced) Then
                maxced = cedemg
                cedpeak(1) = cedtime
            End If
        Loop
    Close #2
Next i3

```

```

'offset
If (cedin = 2 And cedemg < cedmean + (2 * cedsd)) Then
  If (cedtime - cedon(1) > cedoff(2) - cedon(2)) Then
    cedin = 1
    cedon(2) = cedon(1)
    cedpeak(2) = cedpeak(1)
    cedoff(2) = cedtime
    cedon(1) = 0
    cedpeak(1) = 0
    maxced = cedmean
  Else
    cedin = 1
    cedon(1) = 0
    cedpeak(1) = 0
    maxced = cedmean
  End If
End If
'less
'onset
If (cedin = 1 And cedemg < cedmean - (2 * cedsd)) Then
  cedin = 0
  cedon(1) = cedtime
End If
'peak
If (cedin = 0 And cedemg < maxced) Then
  maxced = cedemg
  cedpeak(1) = cedtime
End If
'offset
If (cedin = 0 And cedemg > cedmean - (2 * cedsd)) Then
  If (cedtime - cedon(1) > cedoff(2) - cedon(2)) Then
    cedin = 1
    cedon(2) = cedon(1)
    cedpeak(2) = cedpeak(1)
    cedoff(2) = cedtime
    cedon(1) = 0
    cedpeak(1) = 0
    maxced = cedmean
  Else
    cedin = 1
    cedon(1) = 0
    cedpeak(1) = 0
    maxced = cedmean
  End If
End If
Loop Until EOF(2)
Close 2
If (cedin <> 1 And cedtime - cedon(1) > cedoff(2) - cedon(2)) Then
  cedon(2) = cedon(1)
  cedpeak(2) = cedpeak(1)
  cedoff(2) = 0
End If
'print ced on peak off
Print #255, "emg_" & Format(i3, "##") & ", "; Tab(10); Format(cedon(2), "##.0000000") & ", "; Tab(30);
  Format(cedpeak(2), "##.0000000") & ", "; Tab(50); Format(cedoff(2), "##.0000000")
Next i3
Print #255,
Print #255,
Loop
Close 1
Close 255
Close 254
Next i2
Next i1
Markend:
  Command1.Caption = "Restart"
End Sub

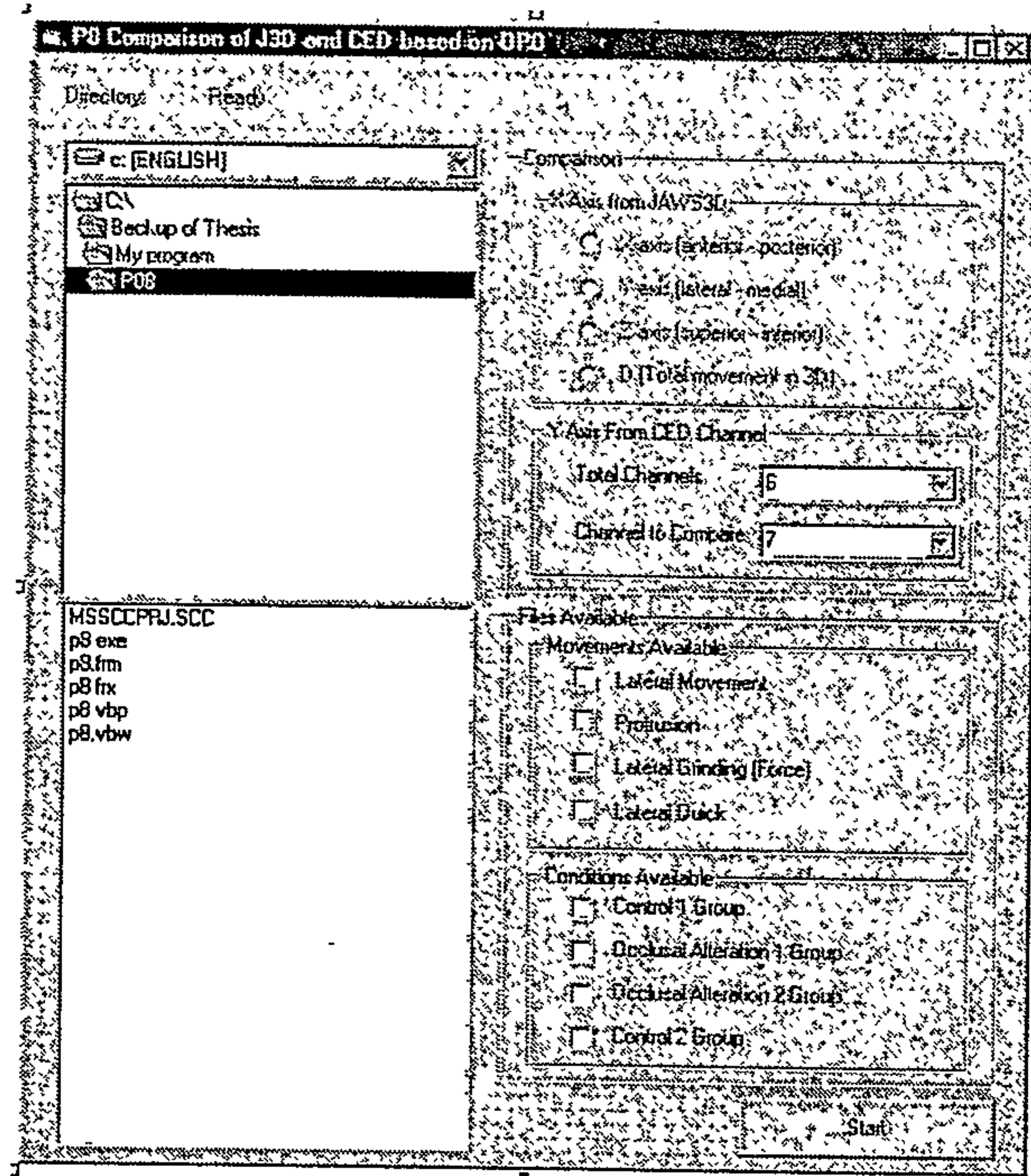
Private Sub Dir1_Change()
  ChDir (Dir1.Path)
  Label2.Caption = CurDir$(Drive1.Drive)
  File1.Path = CurDir$(Drive1.Drive)
  Command1.Enabled = True
End Sub

```

```

Private Sub Drive1_Change()
ChDrive (Drive1.Drive)
Dir1.Path = CurDir$(Drive1.Drive)

```



End Sub

```

Option Explicit
Dim movement As Integer
Dim movem(1 To 4) As String
Dim condition As Integer
Dim cond(1 To 4) As String
Dim temg As Integer
Dim emg As Integer
Dim emgtime(1 To 3) As Double
Dim j3d As Integer
Dim j3ds As String
Dim tj3d(1 To 3) As Double
Dim comp(1 To 3, 1 To 23) As Double

```

```

'dim counter
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim fcount As Integer
'dim local counter
Dim i101 As Integer
Dim i102 As Integer
'dim local input
Dim xstring As String

```

```

Private Sub Check1_Click()
Frame6.Enabled = True
End Sub

```

```

Private Sub Check2_Click()
Frame6.Enabled = True
End Sub

```

```

Private Sub Check3_Click()
Frame6.Enabled = True
End Sub

```

```

Private Sub Check4_Click()
Command1.Enabled = True
End Sub

```

```

Private Sub Check5_Click()
Command1.Enabled = True

```

```

End Sub

Private Sub Check6_Click()
    Command1.Enabled = True
End Sub

Private Sub Check7_Click()
    Command1.Enabled = True
End Sub

Private Sub Check8_Click()
    Frame6.Enabled = True
End Sub

Private Sub Combo1_Change()
    If Val(Combo1.Text) < 1 Or Val(Combo1.Text) > 8 Then Combo1.Text = 6
End Sub

Private Sub Combo2_Change()
    If Val(Combo2.Text) < 1 Or Val(Combo2.Text) > 16 Then Combo2.Text = Val(Combo1.Text) + 1
End Sub

Private Sub Command1_Click()
    Command1.Enabled = False

    'comparison of j3d
    If Option1.Value = True Then j3d = 1: j3ds = "x"
    If Option2.Value = True Then j3d = 2: j3ds = "y"
    If Option3.Value = True Then j3d = 3: j3ds = "z"
    If Option4.Value = True Then j3d = 4: j3ds = "d"
    'comparison of emg
    temg = CInt(Val(Combo1.Text))
    emg = CInt(Val(Combo2.Text))

    'movement available
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: movem(movement) = "wl"
    If Check2.Value = 1 Then movement = movement + 1: movem(movement) = "pro"
    If Check3.Value = 1 Then movement = movement + 1: movem(movement) = "wlf"
    If Check8.Value = 1 Then movement = movement + 1: movem(movement) = "wlq"
    If movement = 0 Then GoTo markend
    'condition available
    condition = 0
    If Check4.Value = 1 Then condition = condition + 1: cond(condition) = "c1"
    If Check5.Value = 1 Then condition = condition + 1: cond(condition) = "oa"
    If Check6.Value = 1 Then condition = condition + 1: cond(condition) = "o2"
    If Check7.Value = 1 Then condition = condition + 1: cond(condition) = "c2"
    If condition = 0 Then GoTo markend

    'processing all movement
    For i1 = 1 To movement
        'open comparision output
        Open ("jc" & movem(i1) & "_" & j3ds & "_" & Format(emg, "##") & ".dat") For Output As #255
        'processing all condition
        For i2 = 1 To condition
            'open input files
            Open ("jc" & movem(i1) & cond(i2) & "_opo.txt") For Input As #1
            Open ("rjc" & movem(i1) & cond(i2) & "_opo.txt") For Input As #2

            'input data
            'clean up data array
            For i101 = 1 To 3
                For i102 = 1 To 23
                    comp(i101, i102) = 0
                Next i102
            Next i101
            'count trial number
            Open ("jc" & movem(i1) & cond(i2) & ".txt") For Input As #3
            fcount = 0
            Do
                Line Input #3, xstring
                If xstring <> "" Then fcount = fcount + 1
            Loop Until EOF(3)
            Close #3
            'set filecount

```

```

For i101 = 1 To 3
    comp(i101, 23) = fcount
Next i101
'each trial
For i3 = 1 To fcount
    'data input
    'initial string
    For i101 = 1 To 2
        For i102 = 1 To 3
            Line Input #i101, xstring
        Next i102
    Next i101
    'j3d data
    For i101 = 1 To 4
        If i101 = j3d Then
            Input #1, xstring, tj3d(1), tj3d(2), tj3d(3)
            If tj3d(3) = 0 Then
                Input #2, xstring, xstring, xstring, tj3d(3)
            Else
                Line Input #2, xstring
            End If
        Else
            Line Input #1, xstring
            Line Input #2, xstring
        End If
    Next i101
    'emg data
    For i101 = (temg + 1) To (temg * 2)
        If i101 = emg Then
            Input #1, xstring, emgtime(1), emgtime(2), emgtime(3)
        Else
            Line Input #1, xstring
        End If
    Next i101
    'end of trial input
    If i3 <> fcount Then
        Line Input #1, xstring
        Line Input #2, xstring
        Line Input #1, xstring
        Line Input #2, xstring
    End If
    'comparison
    If emgtime(3) <> 0 Then
        For i101 = 1 To 3
            comp(i101, i3) = tj3d(i101) - emgtime(i101)
            comp(i101, 21) = comp(i101, 21) + comp(i101, i3)
        Next i101
    Else
        For i101 = 1 To 2
            comp(i101, i3) = tj3d(i101) - emgtime(i101)
            comp(i101, 21) = comp(i101, 21) + comp(i101, i3)
        Next i101
        comp(3, 23) = comp(3, 23) - 1
        comp(3, i3) = 1000
    End If
Next i3
'close input file
Close #1
Close #2
'processing mean
For i101 = 1 To 3
    comp(i101, 21) = comp(i101, 21) / comp(i101, 23)
Next i101
'processing sd
For i3 = 1 To fcount
    If comp(3, i3) <> 1000 Then
        For i101 = 1 To 3
            comp(i101, 22) = comp(i101, 22) + (comp(i101, i3) - comp(i101, 21)) ^ 2
        Next i101
    Else
        For i101 = 1 To 2
            comp(i101, 22) = comp(i101, 22) + (comp(i101, i3) - comp(i101, 21)) ^ 2
        Next i101
    End If
Next i3

```

```

For i101 = 1 To 3
    comp(i101, 22) = (comp(i101, 22) / (comp(i101, 23) - 1)) ^ 0.5
Next i101
'print
Print #255, "Movement: " & movem(i1) & cond(i2); Tab(30); "Comparision: " & j3ds & "_axis vs channel ";
    Format(emg, "##")
Print #255, "List"; ", "; "Onset"; ", "; "Peak"; ", "; "Offset"
For i101 = 1 To fcount
    If comp(3, i101) <> 1000 Then
        Print #255, Format(i2, "00"); ", ";
        Print #255, Format(comp(1, i101), "#0.000"); ", ";
        Print #255, Format(comp(2, i101), "#0.000"); ", ";
        Print #255, Format(comp(3, i101), "#0.000")
    Else
        Print #255, Format(i2, "00"); ", ";
        Print #255, Format(comp(1, i101), "#0.000"); ", ";
        Print #255, Format(comp(2, i101), "#0.000"); ", ";
        Print #255, "*,***"
    End If
Next i101
Print #255, "Mean"; ", ";
Print #255, Format(comp(1, 21), "#0.00"); ", ";
Print #255, Format(comp(2, 21), "#0.00"); ", ";
Print #255, Format(comp(3, 21), "#0.00")
Print #255, "SD"; ", ";
Print #255, Format(comp(1, 22), "#0.00"); ", ";
Print #255, Format(comp(2, 22), "#0.00"); ", ";
Print #255, Format(comp(3, 22), "#0.00")
Print #255,
Print #255,
Next i2
Close #255
Next i1
markend:
    Command1.Caption = "Restart"
End Sub

Private Sub Dir1_Change()
    ChDir (Dir1.Path)
    Label2.Caption = CurDir$(Drive1.Drive)
    File1.Path = CurDir$(Drive1.Drive)
    Frame2.Enabled = True
    Frame1.Enabled = True

End Sub

Private Sub Drive1_Change()
    ChDrive (Drive1.Drive)
    Dir1.Path = CurDir$(Drive1.Drive)

End Sub

Private Sub Option1_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

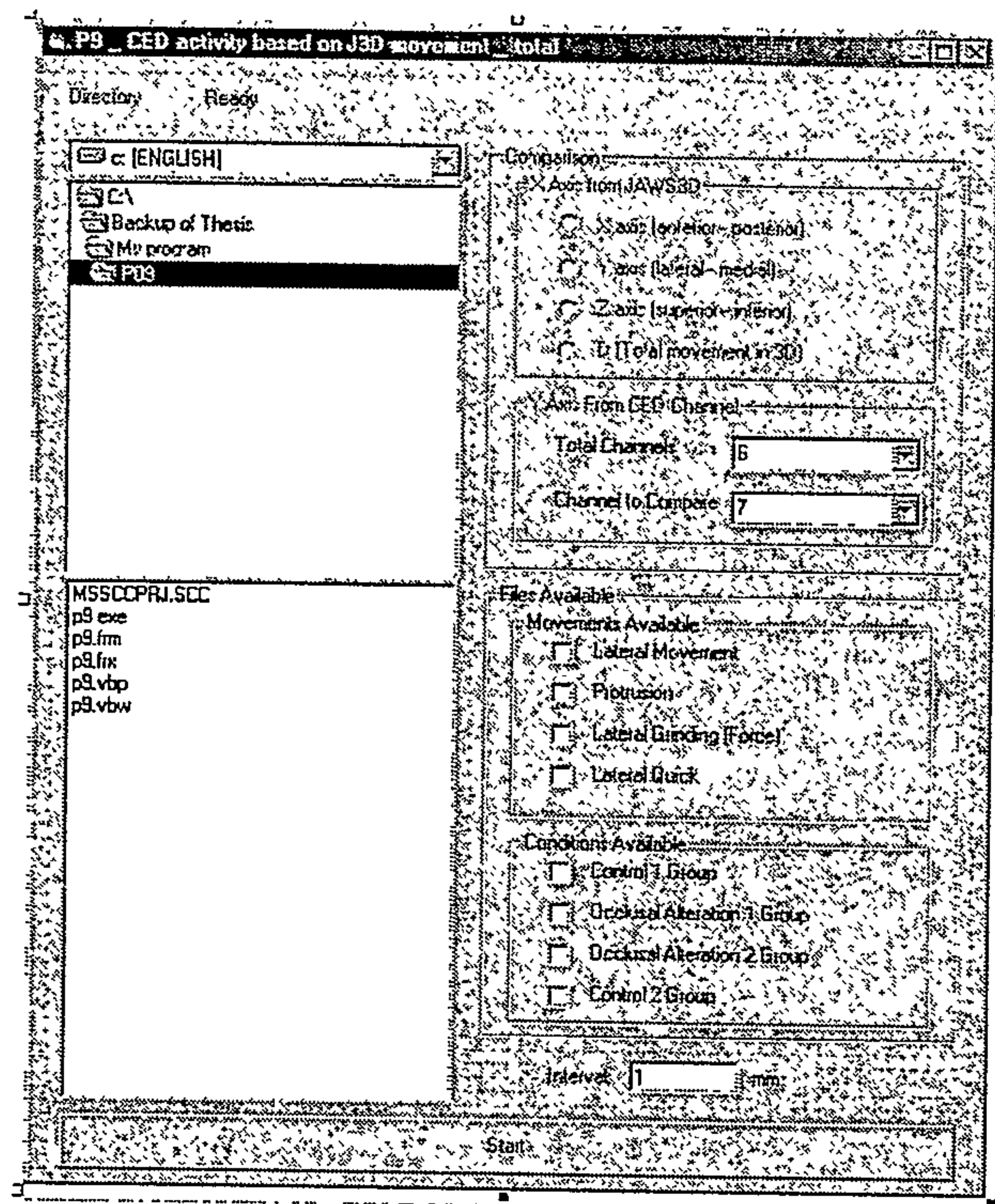
Private Sub Option2_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option3_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option4_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

```

APPENDIX VII



This program calculates the EMG activity (entire mm) of the selected muscle at each mm of the MIPT displacement. This program was written by the PhD candidate.

```
Option Explicit
Dim movement As Integer
Dim movem(1 To 4) As String
Dim condition As Integer
Dim cond(1 To 4) As String
Dim time(1 To 4) As Double
Dim temg As Integer
Dim emg As Integer
Dim emgtc(1 To 2) As Double
Dim emgtime(0 To 100) As Double
Dim emgmean(0 To 100) As Double
Dim emgtotal As Double
Dim rate As Double
Dim tj3d(1 To 2, 0 To 4) As Double
Dim distance As Double
Dim j3d As Integer
Dim j3ds As String
Dim jname As String
Dim ename As String
```

```
'dim counter
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim fcount As Integer
'dim local counter
Dim i101 As Integer
Dim i102 As Integer
'dim local input
Dim x1 As Double
Dim xstring As String
'dim local calculation
Dim xt As Double
```

```
Const enlarge = 1000
```

```

Private Sub Check1_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check2_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check3_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check4_Click()
    Command1.Enabled = True
End Sub

Private Sub Check5_Click()
    Command1.Enabled = True
End Sub

Private Sub Check6_Click()
    Command1.Enabled = True
End Sub

Private Sub Check7_Click()
    Command1.Enabled = True
End Sub

Private Sub Check8_Click()
    Frame6.Enabled = True
End Sub

Private Sub Combo1_Change()
    If Val(Combo1.Text) < 1 Or Val(Combo1.Text) > 8 Then Combo1.Text = 6
End Sub

Private Sub Combo2_Change()
    If Val(Combo2.Text) < 1 Or Val(Combo2.Text) > 16 Then Combo2.Text = Val(Combo1.Text) + 1
End Sub

Private Sub Command1_Click()
    Command1.Enabled = False

    'comparison of j3d
    If Option1.Value = True Then j3d = 1: j3ds = "x"
    If Option2.Value = True Then j3d = 2: j3ds = "y"
    If Option3.Value = True Then j3d = 3: j3ds = "z"
    If Option4.Value = True Then j3d = 4: j3ds = "d"
    'comparison of emg
    temg = CInt(Val(Combo1.Text))
    emg = CInt(Val(Combo2.Text))

    'movement available
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: movem(movement) = "wl"
    If Check2.Value = 1 Then movement = movement + 1: movem(movement) = "pro"
    If Check3.Value = 1 Then movement = movement + 1: movem(movement) = "wlf"
    If Check8.Value = 1 Then movement = movement + 1: movem(movement) = "wlq"
    If movement = 0 Then GoTo markend
    'condition available
    condition = 0
    If Check4.Value = 1 Then condition = condition + 1: cond(condition) = "c1"
    If Check5.Value = 1 Then condition = condition + 1: cond(condition) = "oa"
    If Check6.Value = 1 Then condition = condition + 1: cond(condition) = "o2"
    If Check7.Value = 1 Then condition = condition + 1: cond(condition) = "c2"
    If condition = 0 Then GoTo markend
    'inteval
    distance = Val(Text1.Text)
    'processing all movements
    For i1 = 1 To movement
        'input cutting time
        Open ("p9" & movem(i1) & ".txt") For Input As #1
            time(1) = 0
            For i101 = 2 To 4

```

```

    Input #1, time(i101)
  Next i101
Close #1

'open output file
Open ("p9" & movem(i1) & "_" & j3ds & "_" & Format(emg, "##") & "_out.txt") For Output As #255
Open ("p9" & movem(i1) & "_" & j3ds & "_" & Format(emg, "##") & "_back.txt") For Output As #254
'processing all conditions
For i2 = 1 To condition
  'open j3d emg correlating files for input
  Open ("jc" & movem(i1) & cond(i2) & ".txt") For Input As #1
  For i101 = 254 To 255
    Print #i101, "movement: " & movem(i1) & cond(i2)
    Print #i101, "comparison: " & j3ds & "axis Vs EMG channel " & emg
    Print #i101, "List"
  Next i101

'processing all files
Do
  'get j3d and emg file for input
  Input #1, jname, ename
  Open (jname & ".dat") For Input As #2
  Open ("f" & ename & "_" & Format(emg, "##") & ".txt") For Input As #3
  'outgoing phase
  'clean up array
  For i101 = 1 To 2
    For i102 = 0 To 4
      tj3d(i101, i102) = 0
    Next i102
    emgtc(i101) = 0
  Next i101
  For i101 = 0 To 100
    emgtime(i101) = 0
  Next i101
  'processing j3d data until holding phase
  Do Until tj3d(1, 0) >= time(2)
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
    For i101 = 1 To 3
      tj3d(1, i101) = Abs(tj3d(1, i101))
    Next i101
    tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
    If tj3d(1, j3d) > (distance / 2) + distance * emgtime(0) Then
      xt = (distance / 2) + distance * emgtime(0)
      emgtime(0) = emgtime(0) + 1
      emgtime(emgtime(0)) = (xt * tj3d(2, 0) - xt * tj3d(1, 0) - tj3d(2, 0) * tj3d(1, j3d) + tj3d(2, j3d) * tj3d(1, 0)) / (tj3d(2, j3d) - tj3d(1, j3d))
    End If
    If tj3d(1, j3d) < (distance / 2) + distance * (emgtime(0) - 1) Then emgtime(0) = emgtime(0) - 1
    For i101 = 0 To 4
      tj3d(2, i101) = tj3d(1, i101)
    Next i101
  Loop
  If time(2) > emgtime(emgtime(0)) Then
    emgtime(0) = emgtime(0) + 1
    emgtime(emgtime(0)) = time(2)
  End If
  'calculating emg data first second
  rate = 1
  emgtotal = 0
  Input #3, emgtc(1), emgtc(2)
  Do Until emgtc(1) >= 1 Or emgtc(1) >= emgtime(1)
    emgtotal = emgtotal + emgtc(2)
    Input #3, emgtc(1), emgtc(2)
    rate = rate + 1
  Loop
  rate = rate - 1
  If rate <> 0 Then emgtotal = emgtotal / rate
  Print #255, jname & ",";
  Print #255, Tab(15); Format(emgtotal * enlarge, "0.000"); ",";
  'til 1st period
  Do Until emgtc(1) >= emgtime(1)
    Input #3, emgtc(1), emgtc(2)
  Loop
  'til last period
  For i3 = 2 To emgtime(0)

```

```

rate = 1
emgtotal = 0
Do Until emgtc(1) >= emgtime(i3)
    emgtotal = emgtotal + emgtc(2)
    Input #3, emgtc(1), emgtc(2)
    rate = rate + 1
Loop
rate = rate - 1
emgtotal = emgtotal / rate
Print #255, Tab(15 * i3); Format(emgtotal * enlarge, "0.000"); ", ";
Next i3
Print #255,
'holding phase
Do Until tj3d(1, 0) >= time(3)
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
Loop
Do Until emgtc(1) >= time(3)
    Input #3, emgtc(1), emgtc(2)
Loop
'returning phase
'clean up array
For i101 = 0 To 100
    emgtime(i101) = 0
    emgmean(i101) = 0
Next i101
'determining max displacement and period
For i101 = 1 To 3
    tj3d(1, i101) = Abs(tj3d(1, i101))
Next i101
tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
emgtime(0) = Fix((tj3d(1, j3d) - (distance / 2)) / distance)
rate = emgtime(0) + 1
For i101 = 0 To 4
    tj3d(2, i101) = tj3d(1, i101)
Next i101
'processing j3d data to determinate period and close j3d data
Do Until tj3d(1, 0) >= time(4) - 1
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
    For i101 = 1 To 3
        tj3d(1, i101) = Abs(tj3d(1, i101))
    Next i101
    tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
    If tj3d(1, j3d) < distance * (rate - 0.5) Then
        xt = distance * (rate - 0.5)
        emgtime(rate) = (xt * tj3d(2, 0) - xt * tj3d(1, 0) - tj3d(2, 0) * tj3d(1, j3d) + tj3d(2, j3d) * tj3d(1, 0)) /
            (tj3d(2, j3d) - tj3d(1, j3d))
        rate = rate - 1
    End If
    If tj3d(1, j3d) > distance * (rate + 0.5) Then rate = rate + 1
    If emgtime(0) < rate - 1 Then emgtime(0) = rate - 1
    For i101 = 0 To 4
        tj3d(2, i101) = tj3d(1, i101)
    Next i101
Loop
Close #2
'processing emg data
'first period
rate = 1
Do Until emgtc(1) >= emgtime(emgtime(0) + 1)
    emgmean(emgtime(0) + 1) = emgmean(emgtime(0) + 1) + emgtc(2)
    Input #3, emgtc(1), emgtc(2)
    rate = rate + 1
Loop
rate = rate - 1
If rate <> 0 Then emgmean(emgtime(0) + 1) = emgmean(emgtime(0) + 1) / rate

'til last period
For i3 = emgtime(0) To 1 Step -1
    rate = 1
    Do Until emgtc(1) >= emgtime(i3) Or emgtc(1) > time(4) - 1
        emgmean(i3) = emgmean(i3) + emgtc(2)
        Input #3, emgtc(1), emgtc(2)
        rate = rate + 1
    Loop
    rate = rate - 1

```

```

        If rate <> 0 Then emgmean(i3) = emgmean(i3) / rate
    Next i3
    'til last 1 second
    Do Until emgtc(1) >= time(4) - 1
        Input #3, emgtc(1), emgtc(2)
    Loop
    'last one second
    rate = 1
    Do Until (emgtc(1) >= time(4) Or EOF(3))
        emgmean(0) = emgmean(0) + emgtc(2)
        Input #3, emgtc(1), emgtc(2)
        rate = rate + 1
    Loop
    rate = rate - 1
    emgmean(0) = emgmean(0) / rate
    Close #3
    'output
    Print #254, jname & ",";
    For i3 = 0 To emgtime(0) + 1 Step 1
        If emgmean(i3) <> 0 Then
            Print #254, Tab(15 * (i3 + 1)); Format(emgmean(i3) * enlarge, "0.000"); ",";
        Else
            Print #254, Tab(15 * (i3 + 1)); ",";
        End If
    Next i3
    Print #254,
    Loop Until EOF(1)
    Print #255,
    Print #254,
    Print #255,
    Print #254,
    'close j3d emg correlating files for input
    Close #1
Next i2

'close output file
Close #255
Close #254
Next i1

markend:
    Command1.Caption = "Restart"
End Sub

Private Sub Dir1_Change()
    ChDir (Dir1.Path)
    Label2.Caption = CurDir$(Drive1.Drive)
    File1.Path = CurDir$(Drive1.Drive)
    Frame2.Enabled = True
    Frame1.Enabled = True
End Sub

Private Sub Drive1_Change()
    ChDrive (Drive1.Drive)
    Dir1.Path = CurDir$(Drive1.Drive)
End Sub

Private Sub Option1_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option2_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option3_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True

```

End Sub

Private Sub Option4_Click()

Frame3.Enabled = True

Frame4.Enabled = True

Frame5.Enabled = True

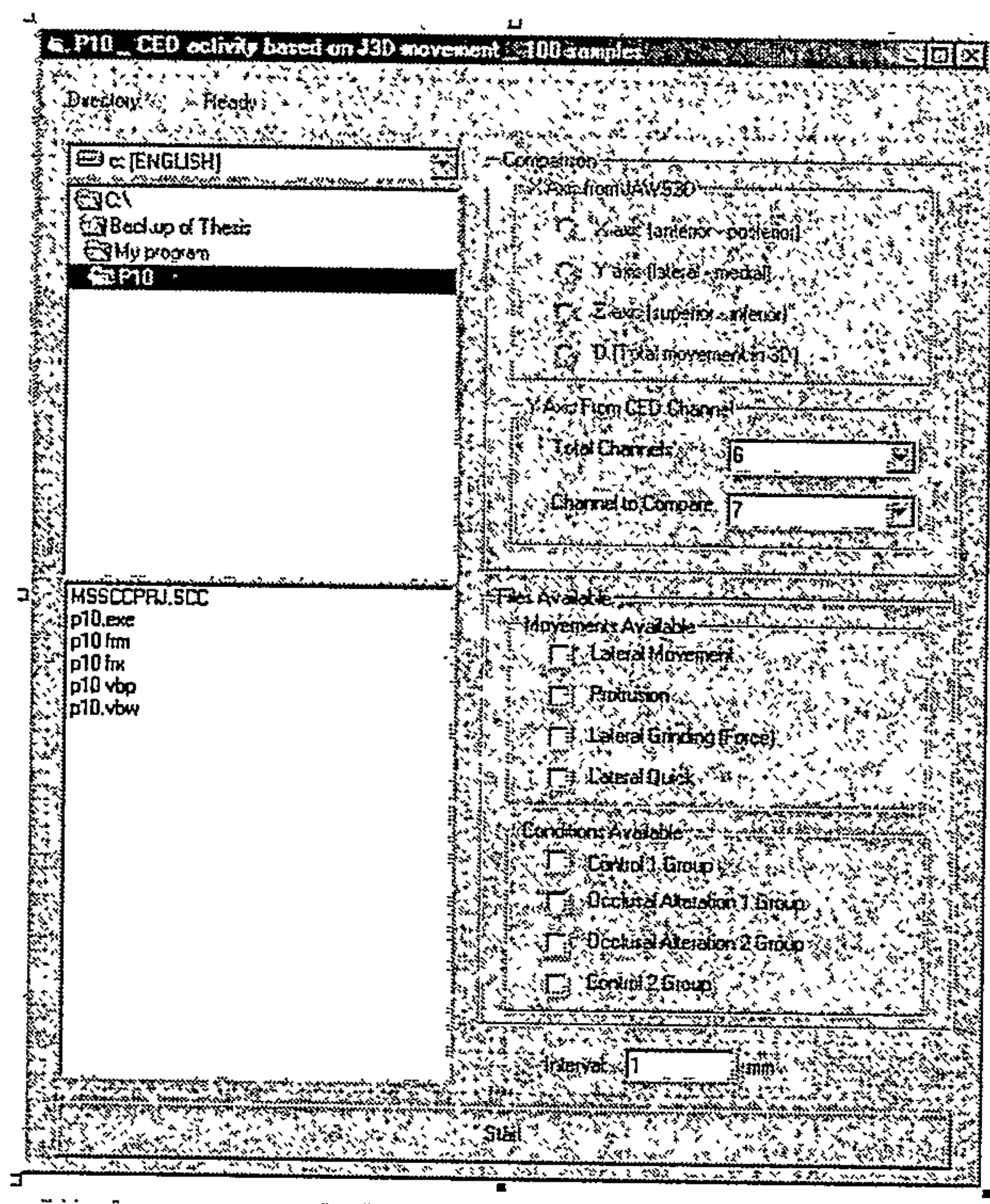
End Sub

Private Sub Text1_Change()

If Val(Text1.Text) <= 0 Then Text1.Text = 1

End Sub

APPENDIX VIII



This program calculates the EMG activity (100 samples) of the selected muscle at each mm of the MIPT displacement. This program was written by the PhD candidate.

```
Option Explicit
Dim movement As Integer
Dim movem(1 To 4) As String
Dim condition As Integer
Dim cond(1 To 4) As String
Dim time(1 To 4) As Double
Dim temg As Integer
Dim emg As Integer
Dim emgtc(1 To 2) As Double
Dim emgtime(0 To 100) As Double
Dim emgmean(0 To 100) As Double
Dim emgtotal As Double
Dim rate As Double
Dim tj3d(1 To 2, 0 To 4) As Double
Dim distance As Double
Dim j3d As Integer
Dim j3ds As String
Dim jname As String
Dim ename As String
Dim pre50 As Double
Const enlarge = 1000
```

```
'dim counter
Dim i1 As Integer
Dim i2 As Integer
Dim i3 As Integer
Dim fcount As Integer
'dim local counter
Dim i101 As Integer
Dim i102 As Integer
'dim local input
Dim x1 As Double
Dim xstring As String
'dim local calculation
Dim xt As Double
```

```

Private Sub Check1_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check2_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check3_Click()
    Frame6.Enabled = True
End Sub

Private Sub Check4_Click()
    Command1.Enabled = True
End Sub

Private Sub Check5_Click()
    Command1.Enabled = True
End Sub

Private Sub Check6_Click()
    Command1.Enabled = True
End Sub

Private Sub Check7_Click()
    Command1.Enabled = True
End Sub

Private Sub Check8_Click()
    Frame6.Enabled = True
End Sub

Private Sub Combo1_Change()
    If Val(Combo1.Text) < 1 Or Val(Combo1.Text) > 8 Then Combo1.Text = 6
End Sub

Private Sub Combo2_Change()
    If Val(Combo2.Text) < 1 Or Val(Combo2.Text) > 16 Then Combo2.Text = Val(Combo1.Text) + 1
End Sub

Private Sub Command1_Click()
    Command1.Enabled = False
    Command1.Caption = "Processing"
    'comparison of j3d
    If Option1.Value = True Then j3d = 1: j3ds = "x"
    If Option2.Value = True Then j3d = 2: j3ds = "y"
    If Option3.Value = True Then j3d = 3: j3ds = "z"
    If Option4.Value = True Then j3d = 4: j3ds = "d"
    'comparison of emg
    temg = CInt(Val(Combo1.Text))
    emg = CInt(Val(Combo2.Text))

    'movement available
    movement = 0
    If Check1.Value = 1 Then movement = movement + 1: movem(movement) = "wl"
    If Check2.Value = 1 Then movement = movement + 1: movem(movement) = "pro"
    If Check3.Value = 1 Then movement = movement + 1: movem(movement) = "wlf"
    If Check8.Value = 1 Then movement = movement + 1: movem(movement) = "wlq"
    If movement = 0 Then GoTo markend
    'condition available
    condition = 0
    If Check4.Value = 1 Then condition = condition + 1: cond(condition) = "c1"
    If Check5.Value = 1 Then condition = condition + 1: cond(condition) = "oa"
    If Check6.Value = 1 Then condition = condition + 1: cond(condition) = "o2"
    If Check7.Value = 1 Then condition = condition + 1: cond(condition) = "c2"
    If condition = 0 Then GoTo markend
    'interval
    distance = Val(Text1.Text)
    'processing all movements
    For i1 = 1 To movement
        'input cutting time
        Open ("p9" & movem(i1) & ".txt") For Input As #1
            time(1) = 0
            For i101 = 2 To 4

```

```

    Input #1, time(i101)
  Next i101
Close #1

'open output file
Open ("p10" & movem(i1) & "_" & j3ds & "_" & Format(emg, "##") & "_out.txt") For Output As #255
Open ("p10" & movem(i1) & "_" & j3ds & "_" & Format(emg, "##") & "_back.txt") For Output As #254
'processing all conditions
For i2 = 1 To condition
  'open j3d emg correlating files for input
  Open ("jc" & movem(i1) & cond(i2) & ".txt") For Input As #1
  For i101 = 254 To 255
    Print #i101, "movement: " & movem(i1) & cond(i2)
    Print #i101, "comparison: " & j3ds & "axis Vs EMG channel " & emg
    Print #i101, "List"
  Next i101

'processing all files
Do
  'get j3d and emg file for input
  Input #1, jname, ename
  Open (jname & ".dat") For Input As #2
  Open ("f" & ename & "_" & Format(emg, "##") & ".txt") For Input As #3
  'outgoing phase
  'clean up array
  For i101 = 1 To 2
    For i102 = 0 To 4
      tj3d(i101, i102) = 0
    Next i102
    emgtc(i101) = 0
  Next i101
  For i101 = 0 To 100
    emgtime(i101) = 0
  Next i101
  'processing j3d data until holding phase
  Do Until tj3d(1, 0) >= time(2)
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
    For i101 = 1 To 3
      tj3d(1, i101) = Abs(tj3d(1, i101))
    Next i101
    tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
    If tj3d(1, j3d) > distance * (emgtime(0) + 1) Then
      emgtime(0) = emgtime(0) + 1
      xt = distance * emgtime(0)
      emgtime(emgtime(0)) = (xt * tj3d(2, 0) - xt * tj3d(1, 0) - tj3d(2, 0) * tj3d(1, j3d) + tj3d(2, j3d) * tj3d(1, 0)) / (tj3d(2, j3d) - tj3d(1, j3d))
    End If
    If tj3d(1, j3d) < distance * emgtime(0) Then emgtime(0) = emgtime(0) - 1
    For i101 = 0 To 4
      tj3d(2, i101) = tj3d(1, i101)
    Next i101
  Loop

  'calculating emg data first second
  rate = 1
  emgtotal = 0
  Input #3, emgtc(1), emgtc(2)
  Do Until emgtc(1) >= 1 Or emgtc(1) >= emgtime(1)
    emgtotal = emgtotal + emgtc(2)
    Input #3, emgtc(1), emgtc(2)
    rate = rate + 1
  Loop
  rate = rate - 1
  If rate <> 0 Then emgtotal = emgtotal / rate
  pre50 = 50 * emgtc(1) / (rate + 1)
  Print #255, jname & ",";
  Print #255, Tab(15); Format(emgtotal * enlarge, "0.000"); ", ";

'til last period
For i3 = 1 To emgtime(0)
  'til beginning of each period
  Do Until emgtc(1) >= emgtime(i3) - pre50
    Input #3, emgtc(1), emgtc(2)
  Loop
  emgtotal = 0

```

```

For i101 = 1 To 100
    emgtotal = emgtotal + emgtc(2)
    Input #3, emgtc(1), emgtc(2)
Next i101
emgtotal = emgtotal / 100
Print #255, Tab(15 * (i3 + 1)); Format(emgtotal * enlarge, "0.000"); ", ";
Next i3
Print #255,
'holding phase
Do Until tj3d(1, 0) >= time(3)
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
Loop
Do Until emgtc(1) >= time(3)
    Input #3, emgtc(1), emgtc(2)
Loop
'returning phase
'clean up array
For i101 = 0 To 100
    emgtime(i101) = 0
    emgmean(i101) = 0
Next i101
'determining max displacement and period
For i101 = 1 To 3
    tj3d(1, i101) = Abs(tj3d(1, i101))
Next i101
tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
emgtime(0) = Fix((tj3d(1, j3d)) / distance)
rate = emgtime(0)
For i101 = 0 To 4
    tj3d(2, i101) = tj3d(1, i101)
Next i101
'processing j3d data to determinate period and close j3d data
Do Until tj3d(1, 0) >= time(4) - 1
    Input #2, x1, tj3d(1, 0), tj3d(1, 1), tj3d(1, 2), tj3d(1, 3), x1, x1
    For i101 = 1 To 3
        tj3d(1, i101) = Abs(tj3d(1, i101))
    Next i101
    tj3d(1, 4) = (tj3d(1, 1) ^ 2 + tj3d(1, 2) ^ 2 + tj3d(1, 3) ^ 2) ^ 0.5
    If tj3d(1, j3d) < distance * rate Then
        xt = distance * rate
        emgtime(rate) = (xt * tj3d(2, 0) - xt * tj3d(1, 0) - tj3d(2, 0) * tj3d(1, j3d) + tj3d(2, j3d) * tj3d(1, 0)) /
            (tj3d(2, j3d) - tj3d(1, j3d))
        rate = rate - 1
    End If
    If tj3d(1, j3d) > distance * (rate + 1) Then rate = rate + 1
    If emgtime(0) < rate Then emgtime(0) = rate
    For i101 = 0 To 4
        tj3d(2, i101) = tj3d(1, i101)
    Next i101
Loop
Close #2
'processing emg data
'til last period
For i3 = emgtime(0) To 1 Step -1
    'til beginning of each period
    Do Until emgtc(1) >= emgtime(i3) - pre50
        Input #3, emgtc(1), emgtc(2)
    Loop
    If emgtime(i3) <> 0 Then
        For i101 = 1 To 100
            emgmean(i3) = emgmean(i3) + emgtc(2)
            Input #3, emgtc(1), emgtc(2)
        Next i101
        emgmean(i3) = emgmean(i3) / 100
    End If
Next i3
'til last 1 second
Do Until emgtc(1) >= time(4) - 1
    Input #3, emgtc(1), emgtc(2)
Loop
'last one second
rate = 1
Do Until (emgtc(1) >= time(4) Or EOF(3))
    emgmean(0) = emgmean(0) + emgtc(2)
    Input #3, emgtc(1), emgtc(2)

```

```

        rate = rate + 1
    Loop
    rate = rate - 1
    emgmean(0) = emgmean(0) / rate
    Close #3
    'output
    Print #254, jname & ",";
    For i3 = 0 To emgtime(0) Step 1
        If emgmean(i3) <> 0 Then
            Print #254, Tab(15 * (i3 + 1)); Format(emgmean(i3) * enlarge, "0.000"); ",";
        Else
            Print #254, Tab(15 * (i3 + 1)); ",";
        End If
    Next i3
    Print #254,
    Loop Until EOF(1)
    Print #255,
    Print #254,
    Print #255,
    Print #254,
    'close j3d emg correlating files for input
    Close #1
Next i2

'close output file
Close #255
Close #254
Next i1

markend:
    Command1.Caption = "Restart"
End Sub

Private Sub Dir1_Change()
    ChDir (Dir1.Path)
    Label2.Caption = CurDir$(Drive1.Drive)
    File1.Path = CurDir$(Drive1.Drive)
    Frame2.Enabled = True
    Frame1.Enabled = True

End Sub

Private Sub Drive1_Change()
    ChDrive (Drive1.Drive)
    Dir1.Path = CurDir$(Drive1.Drive)

End Sub

Private Sub Option1_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option2_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option3_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Option4_Click()
    Frame3.Enabled = True
    Frame4.Enabled = True
    Frame5.Enabled = True
End Sub

Private Sub Text1_Change()
    If Val(Text1.Text) <= 0 Then Text1.Text = 1
End Sub

```