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Changes in cortical activation in craniomandibular disorders during splint therapy – A single subject fMRI study

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SUMMARY

There is some controversial discussion within the therapy of craniomandibular disorders (CMDs) about the mode of action of *occlusal splints*. Here we present a case report on one CMD-patient measuring cerebral activation changes with functional magnetic resonance imaging (fMRI) before and after therapy with a stabilization splint. Wearing the Michigan splint for 11 nights and partially days resulted in substantial pain relief and changes in occlusal movement performance. Cerebral activation during occlusion was decreased after therapy (PRE–POST) in bilateral sensorimotor regions but also additional areas such as left posterior insula, right superior temporal cortex and bilateral occipital lobe. During the first usage of the splint in the scanner (PRE) increased activation in the left dorsolateral prefrontal lobe (BA 9) was observed. After splint training occlusion with the splint compared to without a splint increasingly involved the left superior parietal lobe (BA 7, POST). Whereas BA 9 might be associated with increasing working memory load due to the manipulation with an unusual object, the BA 7 activation in the POST session might document increased sensorimotor interaction after getting used to the splint. Our findings indicate that wearing an occlusion splint triggers activation in parietal sensorimotor integration areas, also observed after long periods of sensorimotor training. These additional recourses might improve coordination and physiological handling of the masticatory system.

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1. Introduction

Occlusal splints are one of the most commonly used treatments of patients with CMD (Ommerborn et al., 2010; Carlsson, 2009) and this therapeutic intervention shows comparable results to other therapeutic methods, e.g. electromyographic biofeedback or relaxation techniques (Schiffman et al., 2007; Kreiner et al., 2001). Neurophysiological effects on the masticatory system and cognitive awareness of harmful behavior might be among other effects (Carlsson, 2009) or possible mechanisms explaining the positive therapeutic effect of an occlusal splint.

However, the influence on the cerebral control of occlusal movement is completely unknown. This is especially astonishing since a cerebral training mechanism induced by these splints might be a major reason for clinical effects achieved. It has been suggested that the presence of the splint as a foreign object in the mouth would likely change the oral tactile stimuli making the patient aware of potentially harmful use of the jaw (Dao and Lavigne, 1998).

Some studies using functional magnetic resonance imaging (fMRI) have investigated cerebral area activation sites during activity of the masticatory system in healthy subjects. Chewing showed predominantly cerebral activation in bilateral primary somatosensory (S1) and motor cortex (M1), secondary somatosensory (S2), premotor cortex (PMC), supplementary motor area (SMA), working memory areas (BA 9 and 10), the parietal cortex, the insula, thalamus, cerebellum but also occipital activation in BA 18 (Onozuka et al., 2002; Shinagawa et al., 2004; Kordass et al., 2007; Lotze et al., in press). Interestingly, these findings correspond with those suggested by Fanghänel et al. (1991) in the "slow reflex" model concerning the regulation of mandible movements.

The aim of the present study has been to demonstrate how cerebral activation changes in conjunction with the use of a stabilization splint in a patient with temporomandibular disorder.

2. Materials and methods

2.1. Patient

A 24 year old woman presented herself at the dental clinic of the Ernst Moritz Arndt University of Greifswald, section for CMD, with the following symptoms: intermittent appearance of pain in

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the left temporomandibular joint, joint sounds on the left side, painful jaw opening movements and painful chewing. She judged her pain intensity at level 4 and her impairment of personal sense of well-being at level 5 (ordinal scale from 0 to 10). There was no history of neurological or psychological illness. Informed consent was obtained from the patient and approval was given by the ethical committee of the medical faculty of the University of Greifswald.

2.2. Clinical exploration

The analysis with the ultrasonic jaw tracking system Jaw-Motion-Analyser (JMA, Comp. Zebris, D-Isny) showed an elongated condylar path of 25 mm excursion length on both sides indicating hypermobility (normal values: 11–15 mm). Jaw opening and closing movements showed an S-shaped deviation. The maximum possible interincisal opening was 50 mm during active mouth opening and 52 mm during passive opening. Additionally, joint clicking was registered on both sides during final mouth opening movements and the beginning of mouth closing movements. The glide path between the retruded contact position and intercuspation was about 1 mm.

A maxillary stabilization appliance of the Michigan type was produced. The splint's position was in projection to the joint region located about 1 mm anterior to that of the intercuspation. The patient wore the splint as much as possible, particularly at night over a period of 11 days.

2.3. Task paradigm

The pre-measurement took place before therapy, when the splint was ready for use, the post-measurement was performed on the day after 11 nights of splint use. Two paradigms were performed during functional imaging: "Occlusion" (opening and closing to centric dental occlusion on natural teeth) and "Splint" (the same tapping movements performed on the stabilization splint). Both movements were performed at a frequency of 1 Hz as indicated by a visual signal projected over a mirror mounted on the head coil. Both tasks were performed in a block design consisting of 9 blocks for each run including 5 "rest" blocks and 4 "action" blocks lasting 3 min and 18 s overall. During the "action" blocks a green display was projected into the patient's field of view and "rest" blocks were indicated with a blue display. The position of the head was fixed using special pillars as head holders in order to fill out spatial distances between head and coil.

2.4. FMRI scanning

FMRI-measurements were performed with a 3 T scanner (Siemens Verio, Erlangen) using a 32-channel head coil. Primarily a T1-weighted high-resolution 3D MPRAGE sequence (TR = 1900 ms, TE = 2.52 ms, 176 sagittal slices, voxel size 1 mm × 1 mm × 1 mm) was acquired. The functional images consisted of echoplanar image volumes which were sensitive to BOLD (blood oxygenation level-dependent) contrast (TR = 2200 ms, TE = 30 ms, 30 slices, voxel size 3 mm × 3 mm × 3 mm).

2.5. fMRI-data analysis

Spatial preprocessing and data analysis were performed with SPM5 (Welcome Department of Imaging Neuroscience, London). Each time-series was realigned and re-sliced after unwarping in phase encoding direction (anterior/posterior). The T1-weighted fMRI scans were co-registered to the functional images, segmented and normalized into the MNI-space which allowed the pre–post comparison and the use of anatomical masks. To correct for intensity inhomogeneities, EPIs were smoothed with a Gaussian filter of 6 mm (FWHM).

In order to analyze changes over time in general we used the comparison "(splint PRE minus POST) + (occlusion PRE minus POST)". In order to differentiate specific cerebral activation sites associated with the splint use before and after training, we calculated the comparison PRE: splint minus occlusion but also POST: splint minus occlusion. For analysis we used FWE (family-wise error) with a p-value of <0.05.

Additionally a ROI-analysis was applied which based on findings on areas involved in occlusal movements but also on first observations on the use of a splint in healthy subjects (see Section 1). The ROI analysis was corrected for the number of voxels within the ROI (FWE; $p < 0.05$).

3. Results

The patient showed a reduction in the pain score on the ordinal scale (0–10) from 4 to 2 and a decrease of her impairment in

Table 1
Global pre minus post effects ((splint PRE minus POST) + (occlusion PRE minus POST)).

Anatomical structure	Brodmann area	MNI-coordinates			t-value
		x	y	z	
Significant BOLD increases					
Right calcarine	30	18	−57	6	6.92
Left precuneus	19	−18	−51	0	6.67
Right cuneus	31	6	−75	21	5.82
Right SMA	6	3	−21	48	5.47
Right superior parietal cortex	Approx. 5	12	−48	63	5.29
Left precentral gyrus	4	−51	−9	30	5.27
Left postcentral gyrus	3	−63	−21	36	5.23
Right precentral gyrus	Approx. 9	51	3	24	5.20
Right lingual gyrus	18	9	−84	−15	5.16
Right postcentral gyrus	3	21	−36	69	5.15
Right paracentral lobule	6	3	−24	72	5.13
Left insula	13	−39	0	6	5.11
Left calcarine	18	−9	−78	12	5.11
Right supramarginal gyrus	1	66	−21	30	5.10
Right superior temporal gyrus	Approx. 42	69	−33	18	5.01
Right supramarginal gyrus	40/S2	63	−18	21	4.91
Left cerebellum crus 1		−45	−75	−27	4.88
Right middle cingulate	24	9	−12	42	4.87
Right precentral gyrus	6	6	−33	72	4.87
Right superior frontal gyrus	6	36	−6	63	4.84

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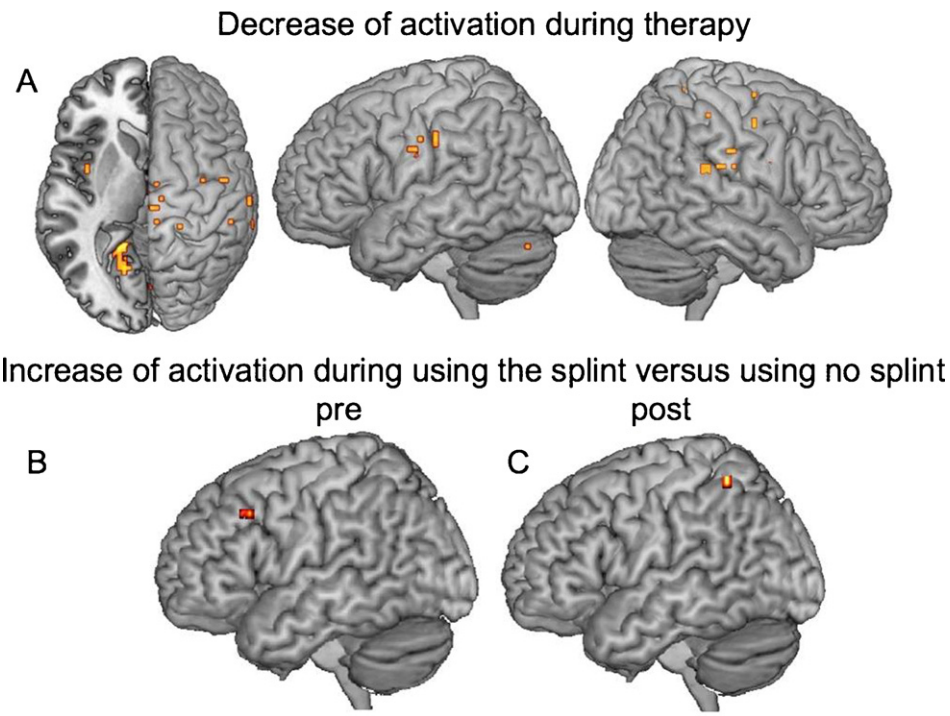

Fig. 1. (A) View of a segmented brain with activation overlay for the top view (left) and the two lateral views. For the top view the left hemisphere was cut in $z = 5$. Activation sites which showed significant reduction by the splint therapy ((splint PRE minus POST) + (occlusion PRE minus POST)) comprised M1, precuneus, insula and cerebellum on the left hemisphere, SMA, PMC, S2, superior parietal cortex, superior temporal gyrus on the right hemisphere and bilateral S1. (B) Activation increase for using the splint before therapy (PRE: splint minus occlusion) showed significant activation in the left middle frontal gyrus (BA 9, DLPFC). (C) Activation increase for using the splint after therapy (POST: splint minus occlusion) showed significant activation in the left superior parietal lobe (approximate to BA 7).

well being from 5 to 1. In respect to the hypermobility as measured with the Jaw-Motion-Analyser the condylar path of 25 mm changed to 20 mm. After 11 nights of splint usage the representation of occlusal movements with and without the splint was drastically reduced ((splint PRE minus POST) + (occlusion PRE minus POST); see Table 1 and Fig. 1A). This was observed in bilateral primary and secondary somatosensory and motor areas, in the left insula, in the occipital and superior right temporal and parietal lobe and left cerebellar hemisphere. The regions of interest (ROI) analysis revealed significant effects in the left middle frontal gyrus (BA 9, dorsolateral prefrontal cortex (DLPFC), $t = 4.41$, coordinates: −39; 24; 39; see Fig. 1B) for the subtraction "PRE: splint minus occlusion". Specific increase of cerebral activation for the splint task after therapy ("POST: splint minus occlusion") was seen in the left superior parietal lobe (approximate to BA 7, $t = 4.91$, coordinates: −42; −5; 60; see Fig. 1C) near the intraparietal sulcus.

4. Discussion

Wearing an occlusal splint intermittently over a period of 11 days and nights resulted in a considerable decrease in cerebral activation during both occlusion on natural teeth and occlusion during splint use. Similar effects on an economization of activation maps after motor training have been described before (e.g. Lotze et al., 2003). In general, a focus on contralateral sensorimotor cortical representation sites and decreased activation in secondary motor areas and cerebellar activation is observed after long time motor training periods. In our case this effect of more focused activation in the course of the therapy might be due to a motor learning process and habituation during therapy. Additionally, in a previous study (Kordass et al., 2007) with healthy subjects, we already described reduced cerebral activation during tapping movements with an occlusal splint compared to without. However, we have to admit that some of these findings in our actual study might be due to habituation to the scanning condition.

We also noticed a decrease in activation of the left posterior portion of the insula after therapy which might be interpreted as an indicator of reduced somatosensory processing but might also be associated with reduced pain processing (Kupers et al., 2004). Whether posterior insular decrease of activation is related to the decreased self-estimation of pain as rated by the patient cannot be shown in this study. Specific increase in cerebral activation for the splint task after therapy ("POST: splint minus occlusion") showed significant activation in the left superior parietal lobe near the intraparietal sulcus (approx. BA 7). This area showed high associations with expert sensorimotor interaction in previous studies (e.g. Lotze et al., 2003). Patients with left hemispheric lesions in this area have been reported to show increased problems with hand movement towards their own body (Halsband et al., 2001), underlying a disturbance of the body-scheme. In our case, the function of the left parietal cortex might be supported by affirmations of the patient about easier coordination of the jaw movements after the therapy, a statement often heard after splint therapy. This feeling was underlined by the biometric investigation indicating a reduced hypermobility.

Before therapy we found specific activations induced by the splint in the left middle frontal gyrus (BA 9) which contributes to the DLPFC. Sakai et al. (1998) ascribed to this area involvement in early motor learning. Several studies showed that this area is involved in working memory processes such as maintenance and manipulation of information (Owen et al., 1999).

To sum up, the afore mentioned information underlies the idea that the splint as a foreign object would likely change the oral tactile stimuli making the patients aware of potentially harmful use of their jaw (Dao and Lavigne, 1998) and thus making it possible to improve coordination and physiological handling of the masticatory system.

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Surprisingly, activation in the occipital lobe (calcarine, cuneus, lingual) was found before therapy. On the one hand it may be due to a patient's initially increased attention towards the visually provided task onset (changing color). On the other hand in an fMRI-study without visual paradigms, investigating tactile object recognition, strong activation in the visual system (occipital calcarine lobe cortex, occipital lobe extrastriatal cortex) has been described earlier, too (Deibert et al., 1999). The explanation they gave about these findings was the fact that visual cortices may be involved in topographic spatial processing of tactile object recognition. In our case this effect might therefore be caused by the unfamiliar use of the splint before therapy.

In conclusion our findings indicate that wearing an occlusion splint might trigger working memory processes initially and result in substantial decrease in motor and somatosensory activation along with clinical improvement. After getting used to the splint, increased left superior parietal activity might reflect improved coordination and sensorimotor integration of movement patterns. Finally, we affirm the following 2 possible mechanisms of an occlusal splint which were named among others by Carlsson (2009): the neurophysiological effects on the masticatory system and the cognitive awareness of harmful behavior.

However, this case report only provides anecdotic information and a group study should provide more information about the different representation maps associated with different clinical outcomes of the splint usage.

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