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fMRI Study on Human Subjects with Sudden Occlusal Vertical Dimension Increase

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Abstract

The aim of this study was to investigate whether immediate sensorimotor activity change and cortical plasticity can be observed over a 2-week period after a change of the occlusal vertical dimension; and whether this data correlates with the individual's psychological profile and satisfaction. Ten subjects (5 males, 5 females) were asked to voluntarily use an acrylic resin mandibular Essex overlay, which provided an increase of 3.0mm at the incisor teeth. Functional magnetic resonance imaging (fMRI) with a tooth-tapping task, as well as satisfaction questionnaire (visual analogue scale -- VAS) were carried out before (T_0), at the insertion (T_1) and at 2 weeks after the insertion of the overlay (T_2). Comparisons were made within the individual's fMRI records. Participants were English speaking and dentate, aged between 18 and 60 years, presenting with no systemic health concerns, no oral disease, dental prostheses or oro-facial pain. VAS data indicated that general satisfaction increased with chewing and speech from T_1 to T_2. fMRI analyses indicated that there were significant changes in medial frontal gyrus, pre-central and post-central gyrus over the 3 recording times ($p<0.007$). fMRI data correlated with psychosocial profiles. Positive sensory and motor cortical plasticity and adaptation from patient feedback can be expected within 2 weeks of increased OVD by 3mm in healthy individuals who are well informed and where there was no actual treatment need.

Keywords: Neuroplasticity; Occlusal Vertical Dimension, fMRI; Teeth-tapping; Adaptation

Introduction

Increase in occlusal vertical dimension (OVD) is a common feature in oral rehabilitation, primarily for: a) managing aesthetics, b) increase in interocclusal restorative space, and c) to alter occlusal relationships [1]. Increasing OVD enables conservation of tooth structure, and a simpler approach for management of the occlusal plane: it provides the option to increase tooth display, re-establish optimal incisal edge position and opportunity to re-design the smile characteristics. Although the evidence available is from case reports and narrative reviews, an increase in OVD by 3-5mm appears to be well tolerated [2-5]. Multiple techniques for determining specific OVD changes are possible and include: a) aesthetic assessment of lower facial height and skin folds, b) pre-treatment records, c) radiographic records and anatomical landmarks (e.g. cephalometric radiograph), d) patient's acceptance of their individual phonetic/speaking space, e) comfort in swallowing, f) subjective sense of comfort/bite force (e.g. with use of a central bearing pin device), g) the amount of restorative space required, and h) possibly objective determination by measuring jaw muscle electromyography (EMG) [6].

It is recognised that some patients may not readily adapt to an increase of OVD. A challenge of dental patient care is that patients who present similar oral status, and who receive similar treatments present patient-specific outcomes. Clinicians encounter patients who return repeatedly with an 'annoying' new single restoration that they report "feels different" irrespective of adjustments. When adaptation to dental treatment does not readily occur, patients may develop a positive occlusal sense, become 'occlusally aware' and may further develop impaired mandibular kinaesthetic perception and possibly chronic jaw pain [7-12]. Animal studies by Sessle and colleagues established that cortical plasticity occurs, not only with major rehabilitation or nerve injury, but also with minor occlusal changes [10]. Cortical changes in edentulous patients restored with implants may be demonstrated using functional magnetic resonance imaging (fMRI) [13], whilst the correlation with patient satisfaction is yet to be determined between the natural dentition, the edentulous state and tooth replacement options.

Successful oral rehabilitation requires adaptation to changes in OVD, tooth position and jaw relationship. However, patients who do not easily adjust may require provisional/diagnostic treatments and longer treatment periods. These susceptibilities, ideally identified before treatment begins, would avoid difficulties in professional relationships and case management. Communication and informed consent is crucial for patient satisfaction. Whilst longevity data are important for treatment consideration and planning, patient satisfaction is linked with clinician-patient communication, involvement in decision-making and adaptation [14,15]. Adaptation to occlusal and prosthesis changes requires investigation of:

i) The time taken for acquisition of new motor skills; and

ii) Neuroplastic changes associated with restoration of function, patient satisfaction and personality profile.

Thus, the aim of this study was to investigate sensorimotor change and cortical plasticity observed over a 2 week period after a change of occlusal vertical dimension, and whether this data correlates with each individual's psychological profile and personal satisfaction.

Materials and Methods

To ensure that the intervention was reversible but relevant to oral rehabilitation, the change provided was an increase in OVD of 3 mm in the incisal region with a removable mandibular acrylic overlay. Facebow and jaw transfer records were used with a Denar Mark II articulator to prepare a replica of the mandibular occlusal arch contour in the occlusal overlay, see Figure 1. The overlay was worn full-time for 2 weeks.

Figure 1. Anatomical form overlay.

Visits	Time	Duration	Procedure
1	T_0	60min	Oral health review and RDC/TMD screening.
			SCL-90-R form completed.
			Impressions of maxillary and mandibular dentitions
			MMR record at intercuspal position
2	T_0	25min set up	fMRI questionnaire with each participant.
		30min	Functional tasks-tooth tappinginstructions and practice given
		recording	Compliance log given
			fMRI recording (T_0) of tooth-tapping task without appliance
	T_1		Appliance will be issued during this fMRI recording
			fMRI recording (T_1) of tooth-tapping task with appliance and
			3D SPGR saggital
			VAS questionnaires (T_1)
3	T_2	25min set up	fMRI safety questionnaire
	2 wks from	15min	fMRI recording (T_2) of tooth-tapping task with appliance
	visit 2	recording	VAS questionnaires (T_2)

Table 1. Timeline and structure of study.

Ten healthy participants, five males and five females were selected based on inclusion and exclusion criteria. Inclusion criteria: (i) participant were dentate to the second molars, orthodontic extraction accepted; (ii) age 18 to 60 years; (iii) optimum general health; (iv) available for recordings. Exclusion criteria: (i) presence of uncontrolled oral disease; (ii) orofacial pain; (iii) anxiety and/or depression; (iv) medical condition; (v) pregnancy; (vi) fixed or removable prosthesis; (viii) orthodontic retainers or aligners; (viii) claustrophobia or other contraindications for fMRI recordings. Dental and temporomandibular joint screening was completed with an oral health review and research diagnostic criteria for temporomandibular disorders assessment [16]. The 10 participants fulfilled the above criteria with age range 27 to 44 ($\bar{x}$ = |31|). All participants were dentists who were aware of the implications of increase OVD. The study protocol is summarized in Table 1. Analyses compared data at T_0 (original state), T_1 (immediately after insertion of overlay) and T_2 (after 2 weeks use of the overlay).

Participants were instructed to wear the occlusal overlay whilst awake (talking, eating and swallowing) and during sleep. They were advised that although oral function would be difficult initially, it would become easier with practice and time. A compliance log book was used to record the time the appliance was actually worn over the whole study period.

The outcome parameters assessed were:

1. **Cortical:** fMRI recording with block design paradigm of a tooth-tapping task at T_0, T_1, and T_2

2. **Psychosocial** – Symptom Check List 90 Revised questionnaire (SCL-90R) for data collection at T_0 and use of a visual analogue scale (VAS) patient satisfaction questionnaire at T_1 and T_2 [17-19].

fMRI Design

Participants were to perform a tooth-tapping task during a block design as recommended by Soltysik and Hyde [20]. Specific instructions were given to participants prior to fMRI recording: tapping with constant rhythm as fast as possible, from resting jaw position and minimal tooth separation, with no head movement.

Recording protocol: each participant lay supine on the scanner table during recordings, their head was immobilized with head pads, and earplugs were provided to reduce auditory discomfort. Earphones were worn for communication with the recording team. Participants were asked to practice the tooth-tapping task as previously instructed. The task paradigm was an alteration between 20 seconds of active task (task-block) and 20 seconds of rest in the rest position (control-block). This on-off procedure was repeated 5 times in each scanning run. After each functional scan, 17.5 min whole brain three-dimensional spoiled gradient (SPGR) T_1 weighted MRI sequence was performed to normalize the data.

Tasks were composed of 3 dummy samples, followed by 5 cycles of 5 control blocks and 5 task blocks which continued alternately for a total of 50 samples. Within individual averages for task blocks and control blocks were used from each recording at each time frame.

The same instructions were given to all participants during the 3 recordings. The first 5 participants received these as voice instructions (3 males and 2 females) whilst the other 5 participants received these as visual instructions (3 females and 2 males). A change in instruction delivery was required due to a later availability of software with the intention to reduce the need for voice instructions over the noise from the MRI unit.

Image Acquisition

Magnetic resonance imaging was performed with a 3.0 Tesla GE HDxTwin speed magnet system (GE Medical Systems, Milwaukee, USA). A total of 50 fMRI volumes were acquired for the task, and the sequence for each task comprised 46 contiguous slices parallel to the inter-commissural (AC_PC) line, with a 4mm thickness and TR=4000ms, TE=35ms, field of view 24x24 cm, and matrix 96x96 with 1 NEX. Three initial 'dummy' volumes were acquired within each sequence to ensure blood oxygen dependent (BOLD) saturation. Each sequence continued for 3 minutes and 32 seconds. Structural MRI 3D T_1-weighted images were acquired in the sagittal plane using a 3D SPGR sequence (TR=8.3ms; TE=3.2ms; Flip Angle = 11°; TI= 500ms; NEX=1; ASSET = 1.5; Frequency direction: S/I). A total of 180 contiguous 1mm slices were acquired covering the whole brain with a 256x256 matrix with an in-plane resolution of 1x1 mm resulting in 1mm^3 isotropic voxels. The 3D SPGR sequence was collected for use in a unified segmentation approach for normalization of the fMRI data to a standard space.

Statistical Analysis

Pre-processing and statistical analysis of fMRI data used Statistical Parametric Mapping (SPM-5 Wellcome Department of Neurology, London, UK). This method was selected based on its public availability and its wide use in neuroscience. Details of the fMRI analysis methodology have been previously described in a recent study investigating neuroplasticity in the adaptation to prosthodontic treatment [21]. Functional scans were realigned, unwrapped, spatially normalized and smoothed to remove movement artefacts and to place data from different subjects into a common anatomical frame. Images were normalized into standardized Montreal Neurological Institute (MNI) space [21] and smoothed using Gaussian kernel (full width at half maximum (FWHM) 8mm).

In the first level fixed effect analysis, a hemodynamic response convolved boxcar function was used to model the BOLD response for the tasks. Contrast images of task vs. rest condition were derived for each participant at each time point (T_0; T_1;

T_2). The individual contrast images were then entered into second-level analyses to show brain regions recruited for the task at each time point. Given the limited sample size, the study used an exploratory threshold of uncorrected p<0.001 data to determine the main regions recruited for this task. Regions of consistent activation across the time points were identified. Percentage BOLD signal for these regions of interest were extracted and were used for comparisons between time points and correlations with other psychosocial variables. Changes in brain activity at the wholebrain level between time points were also assessed by comparing T_1 to baseline T_0 and between T_2 to T_1. Pearson's correlation was used for associations with other variables and to elicit any time dependence.

Psychosocial Profile

In acknowledgement of the descending influences from higher brain centres associated with emotions, recognition of the importance of the dentition, and past dental experiences, psychological evaluation was included. Assessment tools were, as previously cited:

1. **Symptom Check List 90 Revised (SCL-90R)**

This inventory is based on 90 questions related to scores on 9 psychological dimensions and it was completed at T_0. This provided an objective measure of each participant's psychological profile to correlate with fMRI and VAS measures.

2. **Visual Analogue Scale (VAS)**

This tool was used to grade patient satisfaction and was completed at T_1 and T_2.

Group analyses were conducted and intra-individual comparison was made between T_0, T_1 and T_2 to determine potential trends. Variables analysed included: fMRI BOLD signal clusters, VAS scores, and correlations were repeated with psychological inventory and compliance rates.

Results

Compliance of full time wear of the overlay was >80% throughout the study so there was no statistical effect considerations required from compliance. Apart from minor discomfort, there was no complication in use of the overlay.

fMRI

Group analysis of fMRI data at each time point

Figure 2 shows the collective activation from 10 participants at T_0, T_1, and T_2. Brain region activated are summarized in Table 2 [22].

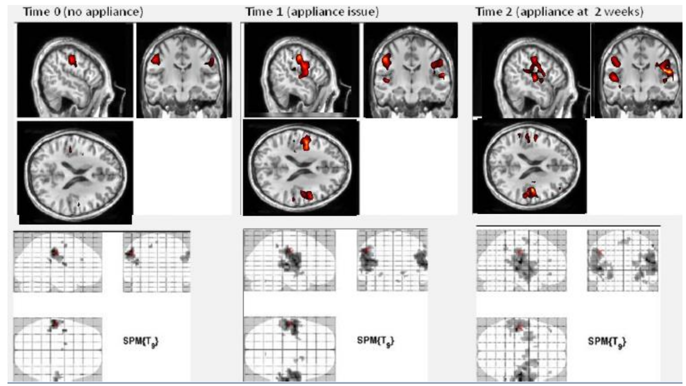

Figure 2. fMRI images from group analyses of the 10 participants over 2 weeks.

Brain Region	Hemisphere	MNI co-ordinates X	Y	Z	Cluster Size no.voxels	T
Original State (T0)						
PostcentralGyrus	Left Cerebrum	-54	-21	39	178*	7.07
PrecentralGyrus	Left Cerebrum	-60	-3	30	178*	5.5
	Right Cerebrum	63	-15	39	92	5.6
Insula	Left Cerebrum	-42	-3	18	14	5.93
Medial Frontal Gyrus	Left Cerebrum	-12	3	54	9	5.35
	Right Cerebrum	51	36	27	4	5.26
*Indicates same cluster						
Immediately after insertion of overlay (T1)						
PostcentralGyrus	Left Cerebrum	-54	-18	42	689^	8.4
PrecentralGyrus	Left Cerebrum	-48	-6	21	689^	8.11
	Right Cerebrum	57	-3	12	562*	7.77
Transverse Temporal Gyrus	Right Cerebrum	66	-21	12	562*	8.37
Inferior Parietal Lobule	Right Cerebrum	60	-39	51	8	5.73
Lentiform Nucleus	Right Cerebrum	18	9	-6	17	5.43
	Left Cerebrum	-24	0	-9	15	4.75
Insula	Left Cerebrum	-30	-24	18	6	4.96
ParahippocampalGyrus	Right Cerebrum	21	-3	-12	8	4.81
Declive	Right Cerebellum	9	-60	-21	4	4.75
Superior Temporal Gyrus	Right Cerebrum	48	-6	0	10	4.72
	Left Cerebrum	-51	6	-6	4	4.56
*^ Indicates same cluster						
After 2 weeks use of overlay (T2)						
Insula	Right Cerebrum	45	-15	21	932^	10.47
	Left Cerebrum	-36	3	15	193*	5.98
Transverse Temporal Gyrus	Right Cerebrum	60	-15	15	932^	10.01
Superior Temporal Gyrus	Right Cerebrum	60	3	3	932^	8.62
	Left Cerebrum	-45	-24	3	596+	9.6
PostcentralGyrus	Left Cerebrum	-48	-21	36	596+	7.02
PrecentralGyrus	Left Cerebrum	-54	0	9	596+	6.79
Inferior Parietal Lobule	Right Cerebrum	57	-45	51	11	8.18
ParahippocampalGyrus	Left Cerebrum	-24	0	-12	193*	6.8
Claustrum	Left Cerebrum	-36	-6	9	193*	4.97
Middle Frontal Gyrus	Left Cerebrum	-39	42	-9	8	6.01
	Right Cerebrum	42	42	21	8	4.85
Medial Frontal Gyrus	Left Cerebrum	0	0	60	59	5.53
	Right Cerebrum	12	-9	63	59	5.26
Inferior Temporal Gyrus	Right Cerebrum	45	-3	-27	7	5.16
Fusiform Gyrus	Right Cerebrum	39	0	-21	7	4.49
*^+ Indicates same cluster						

Table 2. Summary of group analysis for tooth-tapping task (Clusters identified at p=0.001) Co-ordinates are in Montreal Neurological Institute space [22].

At T_0, there was significant activation in both left and right hemispheres of the frontal lobe, parietal lobes and sublobar region (p=0.001). Areas activated in the frontal lobe included precentral gyrus (Brodmann area 4 and 6), the medial frontal gyrus (Brodmann area 6), and middle frontal gyrus (Brodmann area 46); the postcentral gyrus (Brodmann area 3) was activated in the parietal lobe, as was the insula (Brodmann area 13) in the sublobar area.

At T_1, there was significant activation in both left and right hemispheres, showing areas in the frontal and parietal lobe and sublobar regions, as well as temporal, limbic and posterior lobes (p=0.001). Areas that were activated in the frontal lobe included the precentral gyrus (Brodmann area 6); activation in the parietal lobe included the postcentral gyrus (Brodmann area 3), and inferior parietal lobule (Brodmann area 40); in the sublobar area the insula (Brodmann are a13) and lentiform nucleus (Putamen) were activated, temporal lobe activation included the transverse temporal gyrus (Brodmann area 42) and superior temporal gyrus (Brodmann area 22); activation in the limbic lobe included the parahippocampal gyrus (amygdala); and activation in the posterior lobe included the declive.

At T_2, there was significant activation in both left and right hemispheres, showing similar areas as T_1 in the frontal and parietal lobe, sublobar regions, temporal, and limbic area (p=0.001). Areas that were activated in the frontal lobe included the precentral gyrus (Brodmann area 6), middle frontal gyrus (Brodmann area 10 and 47), medial frontal gyrus (Brodmann area 6); activation in the parietal lobe included the postcentral gyrus (Brodmann area 3), inferior parietal lobule (Brodmann area 40); activation in the sublobar was the insula (Brodmann area 13); activation in the temporal lobes included the transverse temporal gyrus (Brodmann area 42) and superior temporal gyrus (Brodmann area 22, 38), inferior temporal and fusiform gyri (Brodmann area 20); and activation in the limbic lobe included the parahippocampal gyrus (Brodmann area 34).

Comparison of whole brain fMRI activity between time points.

Table 3 shows the group subtraction analysis [22]. Figure 3 shows fMRI images from group analyses with subtractions with T_1-T_0 and T_2-T_1.

When collective data of T_0 was subtracted from T_1, immediate changes were detected. The changes demonstrated significant difference and higher activation in the left hemisphere only, frontal lobe, precentral gyrus (Brodmann area 4 and 6) and culmen in the anterior lobe, as well as declive in the posterior lobe.

Group analysis subtraction of T_2 minus T_1 indicated significant difference and increased activation in both the left and right hemispheres, (p=0.001). Areas activated in the frontal lobe included the medial frontal gyrus (Brodmann area 10); activation in the temporal lobes included the middle temporal gyrus (Brodmann area 39).

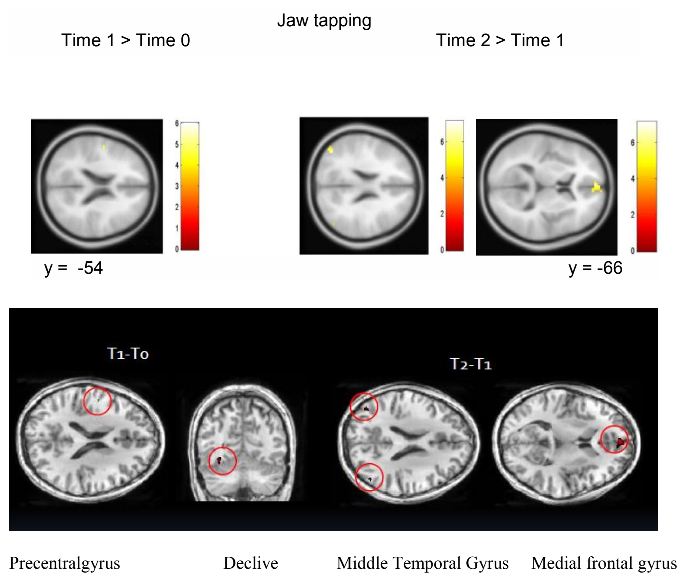

Figure 3. fMRI images from group analyses with subtractions with T_1-T_0 and T_2-T_1.

Brain Region	Hemisphere	MNI co-ordinates X	Y	Z	Voxels Cluster Equiv k	T
Time 1 – Time 0						
Whole Brain						
Declive	Left Cerebellum	-33	-66	-18	8	6.01
Culmen	Left Cerebellum	-15	-27	-15	3	4.84
PrecentralGyrus	Left Cerebrum	-54	-6	21	5	4.55
	Left Cerebrum	-48	-6	27		4.49
Time 2 – Time 1						
Whole Brain						
Middle Temporal Gyrus	Right Cerebrum	51	-66	18	10	7.13
	Left Cerebrum	-45	-72	24	14	6.77
Medial Frontal Gyrus	Left Cerebrum	-3	57	9	23	6.48
	Right Cerebrum	6	54	12		5.09

Table 3. Subtraction of group analysis (Clusters identified at p=0.001) Co-ordinates are in Montreal Neurological Institute space [22].

In Figure 4, all slices were taken at the same level – axial slice 92 and sagittal slice 144. After insertion of the occlusal overlay, the changes in BOLD signals were immediately observed in both pre- and post central gyri, and continued to be significantly different at 2 weeks.

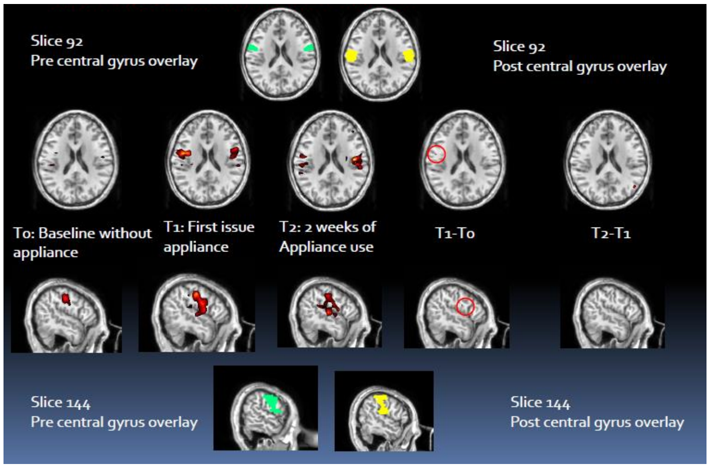

Figure 4. Changes in the pre- and post-central gyrus.
The top and bottom row images refer to the functional anatomical mapping where green indicates the precentral gyrus, the yellow indicates the postcentral gyrus. Red areas in the middle 2 rows are the BOLD signals of group analysis with significance p=0.001.

Analysis of Specific Regions

Data indicated five areas with significant activation throughout this study. These areas were the right and left middle temporal gyrus (function: recognize familiar faces, ascertaining distance and understanding word meaning while reading), medial frontal gyrus (high level executive decision making), precentral gyrus (primary motor cortex) and postcentral gyrus (somatosensory cortex). (Tables 2 and 3) BOLD values from these specific areas for T_0, T_1, and T_2 were used for further analyses. Univariate ANOVA with paired comparisons and Bonferroni corrections to account for multiple comparisons on all variables that had 3 levels was carried out. Significant results with an effect on time were identified only at 3 sites; the left and right middle temporal gyrus, were not significantly different over time:

1. Medial frontal gyrus: effect was p=0.004
i. There was a significant difference between T_1 and T_2 p=0.003

2. Precentral gyrus: effect was p=0.007
i. There was a significant difference between T_1 and T_2 p=0.006

3. Postcentral gyrus: effect was p=0.000
i. There was a significant difference between T_1 and T_2 p=0.000
ii. There was a significant difference between T_0 and T_1 p=0.001.

VAS

A paired t-test on VAS Q1-11 was carried out as data were recorded at T_1 and T_2. Significant differences between T_1 and T_2:

1. VAS Q1 - general satisfaction: all subjects showed improvement over the 2-weeks of appliance use (p=0.000). Spearman's rho correlation found VAS score for Q1 at T_1 was associated with the score at T_2 (r=0.669, p=0.035).

2. VAS Q2 - resemblance with the natural dentition: all but one subject considered that after 2-weeks use, the appliance closely resembled their natural dentition (p=0.039).

3. VAS Q6 – comfort: all but one subject considered that the appliance became more comfortable after 2-weeks use; and one subject demonstrated a value similar with the original score of 70mm (p=0.012).

4. VAS Q10 - the quality of the bolus: all but one subject demonstrated improvement over the 2-weeks (p=0.014).

5. VAS Q9 - ease of chewing: most subjects found that chewing became easier over the 2-weeks (approached significance p=0.056).

SCL-90R

Several of the psychological domains correlated with each other:

1. Paranoid ideation and psychoticism correlated highly (r=0.79, p=0.007) and showed similar patterns throughout the study and correlation with interpersonal sensitivity (r= 0.733, p=0.016), obsessive compulsive (r=0.66, p=0.037) and depression (r= 0.646, p= 0.044).

2. Hostility was highly correlated with obsessive compulsive (r=0.84, p= 0.003), and depression (r= 0.817, p=0.004) levels; and also correlated with paranoid ideation (r=0.743, p=0.014), interpersonal sensitivity (r= 0.673, p=0.033) and somatisation (r= 0.647, p= 0.043).

3. Interpersonal sensitivity correlated with psychoticism (r= 0.705, p= 0.023), anxiety (r= 0.674, p= 0.033) and phobic anxiety (r= 0.645, p= 0.44).

4. Anxiety correlated with phobic anxiety (r=0.782, p=0.008).

SCL90R result correlations with fMRI data

Pearson's correlation (r) between the MRI sites at the right and left middle temporal gyrus, medial frontal gyrus, precentral gyrus, and postcentral gyrus, across all three times T_0, T_1, and T_2 with the SCL-90-R scores, gave the following significant results:

1. At T_0, anxiety correlated with the precentral gyrus (r=0.68,

p=0.03), phobic anxiety correlated with the postcentral gyrus (r=0.68, p=0.032), and somatisation correlated with the postcentral gyrus (r=0.65, p=0.042)

2. At T_1, paranoid ideation correlated with the medial frontal gyrus (r=0.69, p=0.028), as did psychoticism (r=0.74, p=0.015)

3. At T_2, interpersonal sensitivity correlated with the precentral gyrus (p=0.035, r=0.67), as did phobic anxiety (r=0.68, p=0.031).

Discussion

The results from group analysis of fMRI at each time point were consistent with previous data on tooth tapping and clench tasks where activation was located in the sensory, motor and pre-motor cortex, whilst gum chewing tasks only activated the sensory and motor cortex which demonstrated differences between voluntary tasks (tapping and clenching) and rhythmical jaw movement as in mastication [23,24]. Kordass et al also demonstrated a weak but significant difference between natural tooth tapping movements and tooth contact on an occlusal splint [25]. In the present study, at the immediate insertion of the overlay to increase OVD, and after 2 weeks, the temporal, limbic and posterior lobes demonstrated a significant increase in regional brain activity (p=0.001). The increase in auditory signal and processing (Brodmann area 22 and 42) in T_1 and T_2 may be explained by different sounds from tooth tapping with insertion of the overlay, and perhaps participants listened more acutely to the rhythm and/or sound of their tapping. The important observation is that despite the significant signal observed in the middle temporal gyrus at all times, there were no significant changes when subtracting T_0 to T_1 to T_2. This suggests that auditory processing was consistent throughout the study, and does not change or influence the plasticity, which was expected to occur in relation to the increase in OVD. The identification of cluster in Brodmann area 20 (visual processing) may be caused by participants' increased focus on visual or voice instruction at the start and stop of each task during functional recording. The additional involvement of the insula and amygdala at T_1 may have an emotional significance, which may relate to the overlay being a 'foreign object'. The involvement of the putamen suggests learning and there was also increased cerebella activity associated with muscle control and motor skill acquisition. The medial frontal gyrus was involved with high-level function and decision-making processes; [26] its correlation with postcentral gyrus activity at T_1 demonstrated the sensory input of the change in OVD to the processing of the jaw tapping movement. In both precentral and postcentral gyri, despite variations in increase/decrease in BOLD signals immediately following overlay insertion, by T_2 all participants showed increased activity in the precentral gyrus and decreased activity in the post central gyrus compared with T_1. This indicated cortical plasticity associated with adaption observed over the 2 weeks. This also demonstrated neural connectivity changes with sensory processing and recruitment of other sensory receptors upon insertion of overlay, and motor skill acquisition to the new jaw position with increased OVD. There was also more activity from the supplementary cortex at T_2 suggesting that the rhythmic jaw movement was being re-established. The review by Sessle suggested that when change/rehabilitation closely resembles the 'old' or the 'familiar', adaptation is more readily observed [8]. This is consistent with cortical investigations on memory and learning. Human brain function studies have reported that when a learning task involved 'implicit memory', that is, one which involved no previous recognition or memory of the related task, the learning process was slower with skill acquisition. Alternatively, where a learning task involved "explicit memory", where there is memory or recognition of a related task, the learning process is faster by repetition and association [26].

Data indicated that the response of the primary sensorimotor cortex, high-level executive function and decision-making processes were associated with psychological profiles when there is an inter-occlusal change. In the participants' original dentate state (T_0), anxiety correlated with motor activity whilst phobic anxiety and somatisation correlated to the somatosensory activity. This may be explained by the new and foreign setting for the study. Paranoid ideation and psychoticism were related to high level executive function response when the overlay was first issued and jaw tapping tasks were undertaken. Interpersonal sensitivity and phobic anxiety appeared to be correlated with motor activity with the overlay after 2 weeks. Somatisation and anxiety no longer correlated at the third fMRI recording which may be attributed to the participant being accustomed to the study environment.

Patient satisfaction data obtained from VAS showed that post-change satisfaction at 2-weeks (T_2) was more closely related to the satisfaction score immediately after change (T_1) than to other correlates of SCL-90R or fMRI. There were no significant correlations with satisfaction reflected by VAS data, which may result from: i) participants being fully dentate and the occlusal overlay was retentive, ii) although the overlay resembled a fixed appliance as it mimicked tooth contour at an increase OVD, it was not a treatment device and did not serve to improve aesthetics or function, iii) all subjects were dentists and aware of the implications of the occlusal change, iv) functional adaptation alone was not the sole determinant of treatment success.

None of the participants reported joint or muscle pain, which supports the clinical observation that these are not of concern when increasing OVD by 3mm in healthy dentate individuals. The time frame observed for sensorimotor plasticity demonstrated in this study was also consistent with EMG studies which reported an increased EMG activity related to an increase in OVD as a short duration response which would return to base levels within 3 months [27]. A recent fMRI study on patients rehabilitated with new dentures demonstrated that adaptation to the new prosthesis, reflected by brain activity re-established to pre-insertion levels, occurred within 3 months [21].

A change in OVD and resultant change in jaw position is commonly a requirement of oral rehabilitation. The prescription for a new OVD should be determined by multiple considerations with patient feedback on: facial aesthetics (lip and facial support of the lower face), physiological speaking and swallowing space, patient's general well-being and age. It is a subjective change (potentially having explicit memory and motivation as positive influences on the adaptive process) and the OVD increase to restore a patient's appearance would have a positive influence. The use of objective measures such as past patient records, and cephalometric radiographs may be used. Other methods such as jaw tracking devices, jaw muscle stimulating devices (e.g. Myo-monitor) and jaw muscle electromyography as 'diagnostic tools' for determining OVD and jaw relationship in oral rehabilitation is not supported [28]. These methods by default often result in sub-optimal aesthetic results and increased financial and biological cost from over-treatment. Application of a new approach requires validated, specificity and sensitivity tested diagnostic techniques to be compared with a gold standard. The numerical data from these devices have no clinical significance, and are not relevant for diagnosis of jaw pain or dysfunction. The authors are strongly of the view that history and clinical examination with validated protocols such as the Research Diagnostic Criteria for Temporomandibular Joint Disorders (RDC-TMD), and Symptom Check List 90 Revised (SCL-90-R) are ethically and professionally desirable [16]. The final treatment OVD and jaw position should be determined by judicious clinical assessment for each patient's aesthetic and functional expectation, general well-being, motivation and psychological profile which all influence individual's adaptive potential, balanced with conservation of oral tissues and minimising financial, biological and time cost for treatment and maintenance.

These data showed for the first time an association between changes in regional brain activity (derived from fMRI recordings) and psychological characteristics when OVD is increased. The implications of these data are relevant for patient management and indicate benefit in determining a patient's psychological profile and expectation in association with treatment, as a correlate of intraoral change.

Conclusion

This study demonstrated that healthy dentate individuals across an age range of 27-44, adapted readily to an arbitrary OVD opening of 3mm with improvement of function in 2 weeks. fMRI recordings successfully identified regional activity associated with jaw tapping tasks and demonstrated adaptive cortical changes in the precentral, postcentral and medial frontal gyri immediately upon an introduction of OVD change which was sustained over 2 weeks. The study identified consistent fMRI correlation with psychological (SCL-90R) data, where there was evaluation of psychoticism, paranoid ideation, somatisation, interpersonal sensitivity, obsessive compulsive and hostility dimensions. Paranoid ideation and psychoticism correlated with the response when the overlay was first issued and jaw tapping tasks were undertaken. Interpersonal sensitivity and phobic anxiety appeared to be correlated with motor activity with the overlay after 2 weeks. VAS Q1 at T_1 also positively correlated to that at T_2.

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