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Orofacial muscle activity during inner speech and auditory verbal hallucinations: implications for a speech control model

Lucile Rapin¹, Marion Dohen¹, Lionel Granjon¹, Mircea Polosan², Pascal Perrier¹, H el ene L evenbruck¹

¹ DPC, GIPSA-lab, UMR 5216, CNRS, Universit e de Grenoble

² P ole de Psychiatrie et de Neurologie du CHU de Grenoble

Introduction

Auditory verbal hallucinations (AVHs) are a stressful symptom of schizophrenia, affecting 50% to 80% of the patients. AVHs are defined as “a sensory experience which occurs in the absence of corresponding external stimulation of the relevant sensory organ, has a sufficient sense of reality to resemble a veridical perception over which the subject does not feel s/he has direct and voluntary control, and which occurs in the awake state” [1].

Some production theories explain AVHs as a distortion in the production of inner speech (IS) in a way that the verbal thoughts of the patient are perceived as external voices [2-4]. These theories can be implemented in the context of a speech motor control model which includes two internal models [5]. The inverse model computes motor commands based on the intended action and the direct model predicts the sensory consequences of the intended action from a copy of the motor commands. The comparison between the predicted and the actual consequences provides a sense of agency. According to these theories, IS production *per se* is not impaired in schizophrenia; however, deficits could arise in the prediction system, disrupting the feeling of agency. Patients would not be aware that they originated IS and thus perceive it as if it came from another agent, switching it into a hallucination.

Several neuroimaging studies have provided evidence for these theories [6-7]. To further test these theories, the actual presence of motor commands during IS and AVHs can be examined, using electromyography (EMG). Subtle EMG activity has been detected in the speech musculature during verbal mental imagery, silent reading and silent recitation [8-9] suggesting motor command emission during IS. A number of studies indicated an orofacial muscular activity during AVHs; however, the findings were not systematically replicated making it impossible to fully conclude on a speech-related muscular activity during AVHs [10-13]. Moreover, most of the studies positively concluding on a muscular activity associated with AVHs also showed the existence of a faintly audible murmur. The advent of more adapted techniques such as sensitive surface EMG (sEMG), and more robust signal processing has opened up new possibilities of testing motor command emission during AVHs.

The aim of this study was thus to put forward an orofacial activity during inner speech in healthy control subjects and during the occurrence of AVHs in schizophrenia patients. Such an observation would corroborate the hypothesis that IS and AVHs are related and that the latter results from a dysfunction in the prediction system of the former.

Methods

11 French schizophrenia patients and 12 French healthy controls subjects participated in the study. All patients were receiving antipsychotic medication and were experiencing frequent hallucinations at the time of the study. Data were recorded on a Biopac MP150 sEMG system. Bipolar sEMG recordings were obtained from 2 orofacial speech muscles: orbicularis oris superior (OOS) and orbicularis oris inferior (OOI) as well as from the non-dominant forearm flexor (FF) muscle. Three conditions were examined. In the *overt speech reading condition*, subjects were asked to read a corpus including isolated syllables, words and sentences. In the *rest condition*, the subjects were asked to remain silent and not move. The third condition differed between groups: the control group performed an *inner speech reading* task (*ISr*) in which they mentally read the corpus and the patient group underwent a

hallucinatory condition (AVH) in which they were asked to remain silent, not move and not refrain from hearing voices. They were asked to press a button from the beginning until the end of a voice. sEMG Data were filtered and centered. The average values of the peak of the rectified sEMG signal for each condition, each muscle and each participant were calculated.

Results

Video monitoring confirmed that there was absolutely no perceivable facial movement during *ISr* and *AVH*. Overt speech produced higher orbicularis oris (OO) muscle activations compared to rest and to *ISr/AVH*. Overall, the contrast between *ISr/AVH* vs. rest was only marginally significant ($t(11)=1.93$; $p=.08$ / $t(10)=3.36$; $p=.09$). However, for 75% of the healthy subjects, maxima in the OO were higher or equal in *ISr* compared to rest ($F(1,8)=9.51$; $p=.015$), suggesting OO involvement in IS production. *AVH* was also linked to a sEMG activity increase in these muscles. In fact, for the OOI, 54.55% of recorded patients had higher maxima in the *AVH* condition compared to rest and 18.2% had equal values ($F(1,7)=10.62$; $p=.01$). The constant FF muscle activity confirmed that the collected sEMG activity was due to speech production and not to a generalized muscle contraction.

Discussion

Despite marginal statistical significance, the OO activation differences between the *ISr/AVH* conditions and the rest condition suggest that there could probably be a speech related muscular activity during IS and during AVHs. This shows that motor commands are produced in IS and suggests that both internal models (vs. only the direct model) are used in IS. A comparison between subtle proprioceptive feedback and predicted output could provide the sense of agency in IS. Our results also corroborate the production theories according to which AVHs are the consequence of a misattributed IS production: there would be a correct IS production (revealed by muscular activity increase) and a conflict would then take place in the prediction system. Further studies are needed to fully adjust the speech motor control model to AVHs and better understand why AVHs don't occur every time patients produce IS.

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