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BRAIN RESPONSES TO COUNTERINTUITIVE SCIENTIFIC STATEMENTS IN STUDENTS SHOWING HIGH AND LOW SCIENCE COMPETENCE

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Many students hold misconceptions about natural phenomena that can challenge science learning partly because they rely on spontaneously activated intuitions, which can lead to valid answers, but not always. Therefore, giving a scientifically valid answer could sometimes require inhibiting these intuitions. Studies show that experts in science activate (more than novices) brain areas related to inhibitory control mechanisms when correctly evaluating counterintuitive stimuli. However, no study has yet explored whether the activation of inhibitory control mechanisms could be associated with individual differences in science competence. This study recruited fifth grade secondary students (16-18 years old) who benefited from similar scientific training but showing varying levels of conceptual science competence and formed two groups controlled for age, socio-economic status and reading abilities. The low conceptual science competence group had difficulties to correctly evaluate scientific statements while high conceptual science competence group correctly evaluated scientific statements. Participants took part in a functional magnetic resonance imaging (fMRI) session where they were asked to determine if counterintuitive verbal statements associated with a common misconception were scientifically correct or incorrect (e.g. Heart manufactures blood, Plants release carbon dioxide, The Sun is a star). Preliminary results suggest that key brain regions in inhibitory control mechanisms are significantly more activated in the high conceptual science competence group than in the low conceptual science competence group.

Keywords: misconceptions; inhibitory control; fMRI

INTRODUCTION

Learning science can be challenging for high school students. International surveys reveal that a majority of adults who have completed secondary education still have difficulty to give valid explanations to simple scientific phenomena (e.g. Miller, 2012). Since the late 70's, researchers have started to relate conceptual difficulties to the fact that even before they start school students possess pre-existing knowledge on how nature works that is often contrary to scientific understanding of the world and that reveals to be hard to change (diSessa, 2006). For many decades, studies in the field of conceptual change have focussed on the identification of this pre-existing knowledge (alternative conceptions) that students are holding. Today, frequent alternative conceptions in most scientific fields have been identified (e.g. Driver & Easley 1978; Confrey, 1990; Wandersee et al., 1994) and include: *ice is denser that water*, *summer is warmer because the Earth is closer to the Sun*, *a projectile loses force along its trajectory*. Studies have shown, that they are especially persistent, for instance, in mechanics (Brown & Hammer, 2008), electricity (Periago & Bohigas, 2005), natural selection (Brumby, 1984) or photosynthesis (Canal, 1999).

Based on previous work of, for example, the dual-processing in reasoning (Evans, 2010) or the interference of intuition in expressing logical thinking (Fischbein, 1983), some of these models have suggested that alternative conceptions may persist because they rely on deeply anchored intuitions or heuristics (see for example Stavy & Tirosh, 2000; Houdé & Leroux, 2009) that may additionally be reinforced in many real-life situations. For instance, according to Houdé & Leroux (2009), alternative conceptions or heuristics are automatic and spontaneously activated because they represent fast and effective reasoning strategies which very often lead to scientifically correct explanations, but unfortunately not always. Therefore in some contexts reasoning scientifically requires to overcome or inhibit these heuristics. Research in cognitive psychology also supports the idea that developing a conceptual understanding might require to inhibit or to overcome deeply anchored intuitive alternative conceptions. Studies using reaction times have demonstrated a tendency to endorse intuitive explanations in a context of speeded response used to limit the capacity to inhibit initial ideas (Keleman & Rosset, 2009; Kelemen, Rottman, & Seston, 2013).

The relation between counterintuitive concepts and inhibition has been further investigated by brain imaging studies. Masson et al. (2014) and Brault Foisy et al. (2015) compared brain activation patterns between novices and experts in science when they evaluate the correctness of visual physics stimulus, either simple electric circuits exposing the *single-wire* misconception or movies of free falling bodies displaying the misconception according to which *heavier objects fall faster*. Results show that experts, significantly more than novices, activate brain areas associated with inhibitory control mechanisms, a brain function that allows resistance to distractors and interferences (Houdé, 2013): the ventrolateral prefrontal cortex (VLPC) and the dorsolateral prefrontal cortex (DLPC). This suggests that the experts' misconceptions in science have not been transformed during learning; they would rather have remained encoded and must be inhibited in order to answer scientifically. However, to date no study has explored whether the activation of inhibitory control mechanisms might explain why some students who benefited from a comparable scientific training have more difficulty than others to overcome their alternative conceptions. This study examines whether low science competence students might show less activation brain areas associated to inhibitory control mechanisms (VLPC, DLPC) compared to high competence students.

METHOD

Participants

A pool of 524 secondary school students was recruited and screened with respect to their conceptual understanding of science and french reading comprehension. Students were all in last year of secondary school (grade 5 – 16-17 y.o.) and were enrolled in elective science courses. From the entire pool, 100 participants were preselected for the fMRI test session, as follows: first, only right-handed students of excellent french reading comprehension score (i.e. > 90% score to the assessment) were considered. The rationale for selecting only right-handed participants is based on evidence of a larger variability of language lateralization in left-handers (Cai et al., 2013). Within that subsample, a selection of students with comparably low or high conceptual understanding of science was made based on their science assessment score. A sample of 39 participants took part in fMRI session and was divided into two groups of lower (n=19, 10 females) and higher (n=20, 10 females) science competence. There were no significant group difference in chronological age ($t(37)=-0.387$, $p>0.7$) or underprivileged area score ($t(37)=-1.477$, $p>0.14$). Participants reported no abnormal neurological history.

Experimental Design and Procedure

During functional MR imaging, participants were presented with 160 scientific statements and instructed to respond by button press whether the statements were scientifically correct or incorrect. Half of the items were intuitive (e.g. Fire contains heat) and the other half consisted of counterintuitive statements (Ice cubes contain heat). In the counterintuitive condition, statements referred to common spontaneously activated misconception that leads to an incorrect response. An intuitive control condition was added. The intuitive statements were similar to the counterintuitive ones in terms of scientific content (topic or concept), level of analysis (macroscopic, microscopic, etc.) response type (correct of incorrect) and length (number of words and complexity of the sentences). A mixed (buffer) condition was included to prevent habituation and included both intuitive and counterintuitive statements. Imaging was performed on a 3.0 T Tim Trio system (Siemens Medical Systems, Erlangen, Germany) using a 32-channel head coil.

RESULTS

Both low competence (LC) group and high competence (HC) group were more accurate when evaluating intuitive statements compared to counterintuitive ones. Accuracy in the LC group was lower than in the HC group when evaluating counterintuitive statements Surprisingly we observe similar difference when evaluating intuitive statements. fMRI data is currently being preprocessed using SPM12 (Wellcome Department of Imaging Neuroscience, London, United Kingdom). First results suggest that key brain regions in inhibitory control mechanisms are significantly more activated in the high conceptual science competence group than in the low conceptual science competence group.

DISCUSSION AND CONCLUSIONS

This research intends to provide complementary data in order to better understand why learning counterintuitive science concepts might be difficult for some students. As proposed previously by Masson et al. (2014) and Brault Foisy et al. (2015), it is likely that learning science does not mean abandoning alternative conceptions but rather learn to actively inhibit these conceptions when a given situation requires it to give a scientifically valid response.

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