Neural Mechanisms of Hierarchical Planning during Navigation

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1 Introduction

Planning, or making multiple decisions in order to achieve a **goal**, is costful. Efficient planning can be achieved by exploiting hierarchical representations. It has been shown that humans spontaneously chunk abstract spaces into multiple **contexts** in a **hierarchical fashion** [1].

However, it is still unknown whether **representations of context switching** exist in the human brain. To test whether humans plan hierarchically, we designed a novel navigation task where the space of states is intrinsically hierarchical.

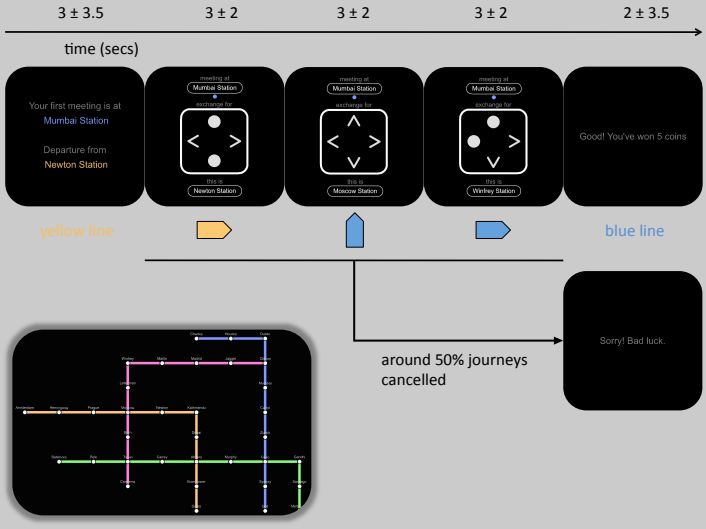
We predicted that context switching would be associated with activation in the **dorsal Anterior Cingulate Cortex** (dACC), a region previously associated with task-switching [2] and tracking the reward value of alternative contexts [3].

Furthermore, we predicted that the **medial Prefontal Cortex** (mPFC), a region previously associated with outcome expectation [3], would track distance to goal.

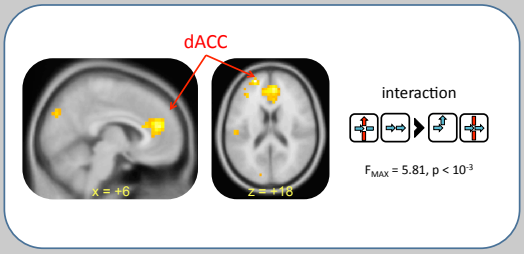
2 Methods

N = 19 participants (age 00±00, 00 males) performed a navigation task within a virtual **subway network** (*station* = state and *line* = context) with which they were familiar, while undergoing **functional Magnetic Resonance Imaging (fMRI)**. The instruction was to minimise the length of all journeys. Completed journeys were economically rewarded after participation (journeys could be randomly cancelled on every step, with fixed probability). The map was shown during a preliminary training session but not during the scanning session. Possible directions (actions) were North / South / East / West. **Regular**, **exchange** and **elbow** stations allowed us to disentangle between effects due to *number of possible directions*, *direction switch*, and *line switch*.

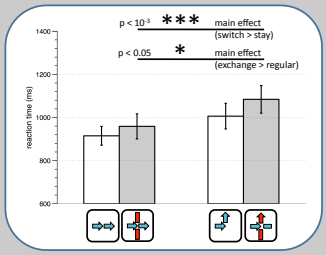
3 Design



4 First Result – dACC signals line switch



General Linear Model (GLM) of BOLD signal

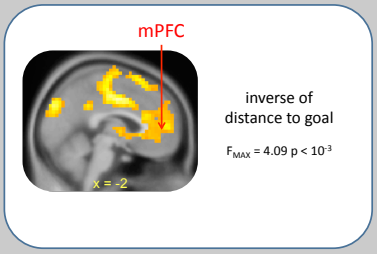


Analysis on Reaction Times (RT)

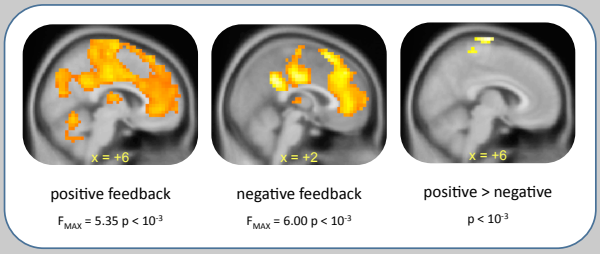
A positive beta weight was found in **the dACC (bilateral)** for the shown interaction. This can be interpreted as the dACC being more activated during **line switch**.

This result is in contrast with Reaction Times (RT), for which main effects of `switch > stay` and `exchange > regular` are significant, but not the interaction.

5 Second Result – mPFC tracks distance to goal but not reward



Distance to goal



Feedback

The same GLM revealed that activity in **mPFC (bilateral) inversely correlates with distance to goal**.

Strikingly, it was consistently activated at the end of each journey (feedback time), independently of the outcome (positive or negative).

6 Discussion

This results provide evidence that humans exploit hierarchical structures during navigation, dividing the space into multiple *contexts*. The **dACC** plays a key role in signalling **context switching** in pursuit of reward. Additionally, we report evidence for a new role of the vmPFC in tracking distance to goal but not reward outcome.

This is in line with previous proposals of a hierarchical organisation of the prefrontal cortex, where resources in anterior regions are allocated to long-term outcomes, in opposition with *posterior* short-term outcomes. However in our study, activation in vmPFC depends on the structure of the task *rather* than outcome.

References

1. **Schapiro et al. (2013)** *Neural representations of events arise from temporal community structure*, Nature Neuroscience
2. **Hyafil, Summerfield, Koechlin (2009)** *Two mechanisms for task switching in the prefrontal cortex*, Journal of Neuroscience
3. **Kolling et al. (2012)** *Neural mechanisms of foraging*, Science
4. **Koechlin, Summerfield (2006)** *An information theoretical approach to prefrontal cortex*

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