**Summary**

The current study seeks to understand the relationship between the neural pathways that are assumed to underpin cognitive control and performance variability observed in mentally demanding tasks, such as multi-tasking paradigms. Specifically, we are interested in tracts between the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC), caudate, and putamen. Diffusion tensor imaging (DTI) methods were used to assess neural tracts.

**Behaviour**

The behaviour that we are interested in is the increase of reaction time variability, as a function of multitasking. We are looking at differences in performance variability, at the intra-individual level.

**Tracts**

We are specifically interested in the role of the tracts between the dorsolateral prefrontal cortex and its connection to the anterior cingulate cortex, the caudate, and the putamen. Activation in the DLPFC and ACC has been shown to be linked to control and selection in attention, with functional connectivity between the two areas increasing with attentional demands (Weissman, Roberts, Visscher, & Woldorff, 2006; Prado, Carp, & Weissman, 2011; Wang et al., 2010). Activation in the DLPFC and the caudate have been shown to be associated with the rate of new learning and are involved in cognitive control and performance monitoring (Yin & Knowlton, 2006; Brovelli, Nazarian, Meunier, & Boussaoud, 2011; Haruno & Kawato, 2006; Balleine & O’Doherty, 2010; Ashby, Turner, & Horvitz, 2010). Similarly, there is involvement of the DLPFC and the putamen in how a conditioned stimulus leads to a correct response and integration of information on how an action may lead to a reward (Brovelli, Nazarian, Meunier & Boussaoud, 2011, Yin & Knowlton, 2006; Haruno & Kawato, 2006; Hikosaka at al., 1999; Ashby, Turner, & Horvitz, 2010). In a functional sense, because the caudate and putamen have competing processes such that one structure will take over or they may need to cooperate; the caudate likely plays a role in the initial learning and understanding phase while the putamen takes over for more well learned tasks (Brovelli, Nazarian, Meunier & Boussaoud, 2011; Haruno & Kawato, 2006; Balleine & O’Doherty, 2010; Ashby, Turner, & Horvitz, 2010). Because of the role of the caudate in cognitive control and performance monitoring, we expect that the caudate will be more involved than the putamen in multitasking. Further, support has been shown for visuomotor control and its interaction with executive function as a left-lateralised function (Gonzalez, van Rootselaar, & Gibb, 2018). Additionally, that the left hemisphere is has an important role in the timing of movements under visual control and anatomical connectivity in the left hemisphere is also important in motor skill (Barber et al., 2012; Floegel & Kell, 2017). Considering the left lateralisation of visuomotor control, it is likely that a tract in the left hemisphere will be more predictive than a tract in the right hemisphere. However, while much of the literature is convergent on left lateralisation in cognitive control, there remains a small number of contrary findings. As such, we are still mindful of any role the right hemisphere may have.

Further, there has been support shown for the convergence of tracts from the ACC to the caudate and putamen respectively (Jarbo & Verstynen, 2015; Seloman & Goldman-Rakic, 1985; Averbeck, Lehman, Jacobson, & Haber, 2014). As mentioned, prior, activation in the ACC and within the caudate and putamen had been shown to be important in executive control, performance monitoring and conditioning behaviours it would be prudent to include. Given that, inclusion of connections between the ACC and caudate and putamen respectively, may provide further explanation of the behaviour we are interested in.

**Data**

The data used here were collected in a previous study run by Garner & Dux (2015); only methods relevant to the current work are discussed here. Garner and Dux collected data from 111 participants, with 11 being removed on the basis of excessive head motion, failure of equipment, dropouts, or systematic error in the sound task, leaving 100 participants. Participants attended six sessions, they first underwent a familiarisation session, followed by the first data collection session that measured their pre-training ability, and collected DTI measures of FA. This was followed by three training sessions where participants trained for the multitasking paradigm, the control group performed a visual search task instead of the multitask paradigm. Proceeding this, a final data collection session was carried out where post training ability was measured with FA values again. Participants used the first two fingers of one hand to press a button that was paired with one of two shapes and/or the first two fingers of the other hand to press a button associated with one of two sounds.

**Hypotheses**

It is hypothesised that tracts between the left DLPFC and the ACC underlie variability processes in multitasking. We also suggest the presence of a relationship between the right DLPFC and the ACC in multitasking variability. This connection is suggested tentatively because previous evidence for the role of the right DLPFC have been present but sparse relative to left hemispheric involvement.

Another tract that may underlie variability is one between the caudate and the DLPFC, this effect should be more predictive in the left hemisphere. Additionally, we speculate that tracts between the putamen and DLPFC will also show an effect, although we hypothesise the putamen potentially tracts in a distinct manner. This is because although the caudate has shown effects in cognitive control and performance motioning, the putamen is more involved with conditioned responses which while important may not be as central to the study at hand. Similarly, we expect connections between the ACC and the caudate and the ACC and the putamen to also have a role in variability processes in multitasking.

To summarise, the tracts that we are interested in are between left DLPFC and ACC, right DLPFC and ACC, right DLPFC to caudate, left DLPFC to caudate, right DLPFC to putamen and left DLPFC to putamen.

**Analysis Plan**

*Reliability Test*

To assess reliability, we will correlate fractional anisotropy (FA) across pretraining and post training sessions from the control group to ensure the data are relatively free from measurement error.

*Data Cleaning*

Reaction time and FA data points that are 3 standard deviations above or below the mean will be removed as outliers (Garner, Tombu, & Dux, 2014). We will calculate the standard deviations (SD) at the participant level and remove data accordingly. Similarly, participants that did not perform the task correctly will be removed from the data set, these are participants who answered incorrectly at a cut-off of 70% and above. We have chosen a 70% threshold so as not to accidentally omit any participants that may have understood correctly the task but still had difficulty responding (Garner, Lynch, & Dux, 2016).

To assess the normality of the data q-q plots and skewness and kurtosis will be calculated. Boxplots will also be assessed to evaluate deviation and outliers in the data to thus determine if any transformations need to be applied.

*Analysis*

Firstly, correlations between FA tracts will be calculated and followed by an exploratory factor analysis, to reduce the number of tracts to a manageable number of factors, while also helping us to understand the underlying structure of how the tracts relate to one another. An EFA would consequently increase statistical power, increase model accuracy and eliminate redundant information and associated noise.

Finally, two multiple regression analyses will be performed. The first will evaluate each participant’s score in the resulting factors derived from the EFA, with a calculated coefficient of variance as the dependent variable. The difference value will be calculated as ‘x = coefficient of variability multitask/coefficient of variability single task’. We sought to determine how variability in performance increased as a function of multitasking opposed to single task performance. To that end, we calculated the variability of each condition and then a ratio between those two variability values. The second regression analysis will test the relationship between participants scores on each of the identified factors and the dependent variable of mean reaction time on multitask divided by single task reaction time. This will ensure that FA measures are predicting variability and it is not that just the mean value and central tendency alone is not influencing the model.

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