PROACTIVE AND REACTIVE COGNITIVE CONTROL IN ADOLESCENCE AND YOUNG ADULTHOOD: NEURAL SIGNATURES AND RELATIONSHIP WITH REWARD DRIVE AND MALADAPTIVE OUTCOMES

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Declarations

STATEMENT OF ORIGINALITY

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

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ACKNOWLEDGMENT OF AUTHORSHIP

I hereby certify that the work embodied in this thesis contains published paper/s/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.
By signing below I confirm that Montana McKewen contributed to the conception and design of the research, data collection, analysis and interpretation of the research data, and the drafting and revision of the publications entitled "Task-switching Costs Have Distinct Phase-locked and Non-phase-locked EEG Power Effects" and "Does cognitive control ability mediate the relationship between reward-related mechanisms, impulsivity, and maladaptive outcomes in adolescence and young adulthood?"

Professor Frini Karayanidis

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Statement of Contribution

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M. McKewen contributed to research design, data collection, EEG data analyses including MATLAB programming, and took the lead role in manuscript preparation. P.S. Cooper contributed to data collection, EEG data analyses including MATLAB programming, and manuscript preparation. A.S.W. Wong contributed to EEG data analyses, including MATLAB programming and manuscript preparation. P.T. Michie contributed to research design and manuscript preparation. P. Sauseng contributed to manuscript preparation and provided expert advice on analyses. F. Karayanidis contributed to research design and manuscript preparation.

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Preface

Cognitive control is an integral part of our day-to-day lives. It enables goal-directed behaviour by inhibiting automatic responses, helping us flexibly switch between different task requirements, and keeping us on track towards the current goal. Cognitive control can be applied proactively in anticipation of a goal, or reactively in response to a change in the goal or the environment (Braver, 2012). Variability in cognitive control is associated with many life outcomes such as mental health, physical health, as well as overall quality of life (Diamond, 2013; Moffitt et al., 2011). Poor cognitive control is also associated with increased engagement in risk-taking behaviours, particularly in adolescence and young adulthood (Magar, Phillips, & Hosie, 2008; Peeters, Oldehinkel, & Vollebergh, 2017).

This thesis aims to first contribute to the characterisation of the neural mechanisms involved in both proactive and reactive control using a cued-trials task-switching paradigm. This paradigm is unique in that it allows the investigation of proactive and reactive control processes within the same task. Using time-frequency analyses, previous research has demonstrated an important role of theta activity in cognitive control processes (e.g. e.g. Cavanagh & Frank, 2014; Cavanagh, Zambrano-Vazquez, & Allen, 2012). This thesis will extend this work by examining the role of theta activity in proactive and reactive control processes engaged during task switching. The first half of this thesis will characterise localised frontal and parietal activity, and global frontoparietal networks associated with proactive and reactive control processes, and examine whether these measures predict behaviour on the task-switching paradigm. The second half of this thesis will examine whether these measures defined in these studies can predict real-world outcomes, such as engagement in risk-taking behaviours, mental health and overall wellbeing, in adolescents and young adults. That is, the second half of this thesis will determine the role of these frontoparietal networks in predicting reward drive, real-world risk-taking behaviours, and outcomes.

This thesis is organised as follows. In Chapter 1, I define and review the current literature on cognitive control and the frontoparietal networks that underpin cognitive control processes, and provide an overview of key theoretical models of cognitive control, including Braver's Dual Mechanisms of Control. I organise this discussion by differentiating between the role of localised frontal and parietal regions, and then the role of the network as a whole. As I argue above, the task-switching paradigm is especially useful in distinguishing proactive and reactive control processes, and is used extensively in this thesis. Therefore, I review the task-switching literature and discuss how the localised frontal and parietal activity and global frontoparietal networks function in this task.

Chapter 2 provides an overview of the Age-ility Project. This thesis uses data from the first phase of the Age-ility Project, a longitudinal study of cognitive control development in adolescence and young adulthood. This chapter outlines the protocol of the Age-ility Project and the measures used in this thesis.

Chapter 3 is the first experimental chapter. This chapter focuses on localised frontal and parietal activity by examining the role of phase-locked and non-phase-locked activity elicited during the task-switching paradigm. This methodology allowed me to differentiate between transient phase-locked effects and more sustained non-phase-locked effects contributing to switching and mixing tasks. This study found that effects of switching and mixing tasks were evident in both phase-locked and in non-phase-locked theta power. However, only non-phase-locked power predicted RT cost and this was only the case for the mixing cost. This suggests a unique role of ongoing theta activity in reducing the cost of mixing tasks.

Chapter 4 focusses on the global properties of the frontoparietal networks. In this study, I targeted only theta activity because both Chapter 1 and our previous work showed that theta produces the most robust and consistent findings in our task-switching paradigm. Using a phase-based measure of connectivity, I examined whether the pattern and strength of connectivity between frontal and parietal sites varied for proactive and reactive control processes. This study found that the similar networks underlie proactive and reactive control processes, both showing strong mid-frontal to bilateral parietal connectivity. However, the way in which these networks function is different. The proactive control network showed progressive increases in connectivity with greater cognitive control demands. In contrast, the reactive control network shows minimal condition differences, suggesting a more task general network. Moreover, both networks were predictive of behaviour, with increased engagement of proactive and reactive networks resulting in a faster RT.

Chapter 5 examines the association between cognitive control and real-world outcomes such as engagement in risk-taking behaviours and poor mental health. This chapter reviews the development of cognitive control and reward systems across adolescence, and discusses models of how differences in the rate of developmental of these systems can lead to poorer outcomes, such as increased risk-taking behaviours and poor mental health. I then discuss evidence for these models by reviewing literature investigating the relationships between the control system (i.e. the local frontal and parietal regions and global frontoparietal networks underlying cognitive control) and measures of reward drive, risk-taking and mental health.

Chapter 6 is the third experimental chapter. This study investigated whether cognitive control mediates the relationship between impulsivity and real-world behaviours, such as engagement in risk-taking behaviours, mental health and overall quality of life. We also looked at this mediating effect on the relationship between reward drive and these outcomes. Cognitive control was measured using both performance-based and experimental measures, including neuropsychological assessments and the cued-trials task-switching paradigm, as well as local EEG measures associated with this paradigm. We found that self-reported cognitive control ability mediated the relationship between self-reported impulsivity and self-reported mental health and overall quality of life. However, there were no significant mediating effects of the performance-based measures of cognitive control (i.e. the EEG and behavioural measures associated with the task-switching paradigm). This finding may indicate that the subjective belief about one's cognitive ability impacts the relationship between impulsivity and outcome behaviours, but objective measures of cognitive ability do not. Alternatively, some research has suggested that it is not localised regions of the brain that are associated with reward drive, impulsivity, and risk-taking, but the networks in the brain.

Thus, Chapter 7 uses the measures developed in Chapters 3 and 4 to examine whether variability in the properties of frontoparietal networks mediates the relationship between impulsivity, reward drive, and outcome behaviours. These measures tapped into the global properties of the frontoparietal networks (Chapter 4), and also provided more sensitive measures of the local frontal and parietal activity (Chapter 3). This study found that there were significant associations between the frontoparietal network measures and reward drive, impulsivity, and outcomes, with reduced frontoparietal network activity correlating with increased reward drive, increased reward drive, and poorer outcomes (i.e. increased risk-taking behaviour and poorer mental health). However, these cognitive control measures did not mediate the relationships between reward drive/impulsivity and outcome behaviours.

Finally, in Chapter 8, I summarise the key findings of this thesis and discuss their contribution to current understanding of the neural basis of cognitive control processes and the role of cognitive control in regulating behavioural outcomes.

Abstract

Over the last two decades, there has been extensive research into adolescent brain development. This research has informed developmental models of adolescent behaviour. These models suggest that an increase in risk-taking behaviour during adolescence arises as a result of an underdeveloped cognitive control system, and an overactive reward system. However, evidence for these models is inconsistent. This thesis aimed to further develop our knowledge of the neural underpinnings of cognitive control and elucidate the relationships between cognitive control, reward drive, impulsivity, and outcomes across adolescence and young adulthood. The thesis extended our knowledge of the frontoparietal networks underlying proactive and reactive control using a cued-trials task-switching paradigm and concurrent electroencephalogram (EEG). Time-frequency power and event-related potential (ERP) analyses was performed on the EEG data to measure localised frontal and parietal activity. Time-frequency connectivity analyses were performed to measure global activity (i.e. connectivity between frontal and parietal regions) within frontoparietal networks. The first half of this thesis found that frontal and parietal power, and frontoparietal connectivity were associated with improved performance on the cued-trials task-switching paradigm in both proactive and reactive control periods. In line with previous research, the majority of these effects were in the theta band (~4-8 Hz). Then, using these localised power and global network measures, the second half of this thesis examined developmental differences in cognitive control and its neural underpinnings across adolescence into young adulthood, and how these differences relate to reward drive and outcomes. Frontal and parietal power and frontoparietal connectivity did not differ as a function of age. However, ERP components associated with task-switching were larger for adolescents compared to adults. The ERP, frontal and parietal power, and frontoparietal connectivity were only weakly related to reward drive or impulsivity. However, self-reported cognitive control ability significantly mediated the relationships between impulsivity and psychological distress, and impulsivity and quality of life. Interestingly, age did not moderate this effect. These findings demonstrate the importance of accounting for individual differences when

investigating relationships between cognitive control, impulsivity, reward drive, and outcomes to produce a more individualised account of adolescent behaviour.

Abbreviations

Experimental	
AX-CPT	AX-Continuous Performance Task
CI	Confidence Interval
CTI	Cue-to-Target Interval
DDTBOX	Decision Decoding Toolbox
FDR	False Discovery Rate
HREC	Human Research Ethics Committee
ICA	Independent Components Analysis
ITI	Inter-Trial Interval
MVPA	Multivariate Pattern Analysis
PCA	Principle Components Analysis
RA	All-Repeat
RCI	Response-Cue Interval
RM	Mixed-Repeat
RT	Reaction Time
SD	Standard Deviation
S-R	Stimulus-Response
ST	Switch-To
SVM	Support Vector Machine
Neuroanatomical	
aCC	Anterior cingulate cortex
dlPFC	Dorsolateral prefrontal cortex
dmPFC	Dorsomedial prefrontal cortex
FEF	Frontal eye field
IFC	Inferior frontal cortex
IFG	Inferior frontal gyrus
IFJ	Inferior frontal junction
IPS	Intraparietal sulcus
lPFC	Lateral prefrontal cortex
mPFC	Medial prefrontal cortex
mSPL	Medial superior parietal lobule
NAcc	Nucleus accumbens
OFG	Obitofrontal gyrus
PFC	Prefrontal cortex
PPC	Posterior parietal cortex
pre-SMA	Pre-supplementary motor area
pSPL	Posterior superior parietal lobule
SMA	Supplementary motor area
vlPFC	Ventrolateral prefrontal cortex
Neuroimaging	
BOLD	Blood-Oxygen-Level-Dependent
CMS	Common Mode Sense
CNV	Contingent Negative Variation
CSD	Current Source Density
DRL	Driven Right Leg
DWI	Diffusion Weighted Imaging
EEG	Electroencephalogram
ERN	Error-Related Negativity
ERP	Event-Related Potential
FA	Fractional Anisotropy

fMRI	Functional Magnetic Resonance Imaging
FRN	Feedback-Related Negativity
ISPC	Inter-Site Phase Clustering
ITPC	Inter-Trial Phase Clustering
MD	Mean Diffusivity
MRI	Magnetic Resonance Imaging
rs-FC	Resting State Functional Connectivity
SPN	Stimulus-Preceding Negativity
tf	Time-Frequency
Psychometric	
BIS/BAS	Behavioural Inhibition Scale/Behavioural Activation Scale
BIS-11	Barratt Impulsivity Scale-11
BRI	Behavioural Regulation Index From The Behavioural Rating Inventory Of Executive Function (BRIEF)
BRIEF	Behavioural Rating Inventory Of Executive Function
CARE	Cognitive Appraisal Of Risky Events
CARE-1	Cognitive Appraisal Of Risky Events – Past Event Frequency
CARE-2	Cognitive Appraisal Of Risky Events – Perceived Risk Benefit
DASS	Depression, Anxiety, And Stress Scale
DERS	Difficulty In Emotional Regulation Scale
General-EF	General Executive Functioning
K10	Kessler Psychological Distress Scale
MI	Metacognition Index From The Behavioural Rating Inventory Of Executive Function (BRIEF)
SBQ	Suicidal Behaviour Questionnaire
SSS	Sensation Seeking Scale
WHO-QoL	World Health Organisation Quality Of Life Scale
WM-Span	Working Memory Span
Neuropsychological Tasks	
CGT	Cambridge Gambling Task
IST	Information Sampling Task
SOC	Stockings Of Cambridge
SSP	Spatial Span
SWM	Spatial Working Memory
TMT	Trail Making Test
WAIS-IV	Wechsler Adult Intelligence Scale - Iv
WASI-II	Wechsler Abbreviated Scale Of Intelligence - II
Theories	
CRUNCH	Compensation-Related Utilisation Of Neural Circuits Hypothesis
DMC	Dual Mechanisms Of Control
Units Of Measurement	
µV	Microvolts
µV/cm^2	Microvolts Per Centimetre Squared
BF	Bayes Factor
cm	Centimetre
dB	Decibel
ms	Milliseconds
Other	
AIHW	Australian Institute of Health and Wellbeing