The nature, ontogeny, and phylogeny of episodic foresight

Jonathan Redshaw

A thesis submitted for the degree of Doctor of Philosophy at
The University of Queensland in 2014
School of Psychology
Abstract

Much attention has recently been given to the psychological capacity for ‘episodic foresight’, which involves imagining, preparing for, and actively shaping specific future events. Because of the relative youth of the field, however, many questions about the nature, ontogeny, and phylogeny of this capacity remain unanswered. Here I present a number of theoretical perspectives and empirical investigations that attempt to answer some of these questions.

In Chapter 2, I provide the first review of evidence for the development of numerous cognitive components that have been implicated in episodic foresight, and the future-oriented behaviours these components enable. I find that the components develop along varying trajectories throughout childhood and beyond, but between ages three and five critical milestones are achieved in each of them. And indeed, around this time children also begin to show evidence of flexible future-oriented behaviour in diverse contexts. I then present four chapters describing empirical studies of novel future-oriented behaviours in children around these ages.

In Chapter 3’s study, I measured children’s capacity to recall a problem from the past and select an object that could solve that problem in a deferred future episode. Previous studies assessing children’s future-oriented object selection had involved future episodes that were merely hypothetical or occurred immediately after the selection. I found that 4-year-olds could remember a problem from 15 minutes ago in another room, and select an object that would solve the problem upon return to the room after a 5-minute sand-timer had completed a cycle. When compared with previous findings, this result suggests that acting for a deferred future episode may place no extra demands on children’s episodic foresight than acting for an immediate future episode.

In Chapter 4’s studies, I measured children’s capacity to seek information that would only be useful in a specific future episode. This behaviour forms a crucial aspect of human learning (e.g., during schooling), but studies had so far focused only on children’s information seeking to achieve an immediate goal. In Study 1 (two experiments), I again used the two-room paradigm to show that many 5-year-olds could recall a problem from the past and seek information to solve that problem in the future. Four-year-olds did not perform above chance level when low-level associative explanations were controlled for, but it remained unclear what caused their poor performance. In Study 2, I relaxed memory demands and gave children the opportunity to seek information in the same context as the future problem. Again, 5-year-olds but not 4-year-olds performed above chance level, although even the older children did not perform at ceiling level.

In Chapter 5’s study, I measured children’s capacity to remember to carry out an intended action at a particular future time, in both the presence and absence of cues to perform the action. Previous studies of time-based prospective memory had included event-based cues (e.g., a visible clock) that can externally remind participants when to perform the crucial action. I administered 3-,
4-, and 5-year-olds a novel paradigm in which they had to remember to ring a bell at the end of a 1-minute sand-timer’s cycle, while also engaged in a secondary ongoing activity. I found that most 4-year-olds could remember to ring the bell when the passage of sand through the timer was visible, but even 5-year-olds struggled when the passage of sand was hidden.

In Chapter 6’s study, I measured children’s capacity to prepare for multiple, mutually exclusive outcomes of a single future event. Previous studies of this capacity had included complex intermediate steps between the preparatory behaviour and the future outcome, while also relying heavily on language comprehension. I designed a novel minimalist task in which 2-4 year-olds were given the opportunity to catch a ball dropped into a forked tube with one opening at the top but two openings at the bottom. I found that many 3-year-olds and most 4-year-olds spontaneously covered both bottom openings of the tube in their first attempt to catch the ball, suggesting they possessed insight into the task contingencies and some understanding of future uncertainty. Many younger children demonstrated their capacity to cover both openings on later trials, but the particular pattern of results suggested this may have been due to simple trial-and-error learning.

Because the paradigm used in Chapter 6’s study has minimal language demands and relies on simple behavioural responses, I was also able to administer a preliminary test to three chimpanzees. None of these subjects spontaneously prepared for both potential outcomes of the immediate future event on the first trial, although one learned to reliably do so after many trials. In Chapter 7, I expand on a discussion point raised by these findings, and present a novel theoretical perspective suggesting that non-human animals may lack one of the crucial components of episodic foresight (metarepresentation) described at the beginning of the thesis.

In Chapter 8, I conclude with a general discussion summarising the empirical findings and making detailed suggestions for future research. I also provide an age-based analysis of the overall results, suggesting they offer additional evidence for the proposal that children’s episodic foresight shows important developments throughout the preschool years. Finally, I revisit the componential analysis of episodic foresight and recommend some additions and alterations to the components in light of my novel empirical findings and theoretical proposals.
**Declaration by author**

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

I acknowledge that an electronic copy of my thesis must be lodged with the University Library and, subject to the General Award Rules of The University of Queensland, immediately made available for research and study in accordance with the *Copyright Act 1968*.

I acknowledge that copyright of all material contained in my thesis resides with the copyright holder(s) of that material. Where appropriate I have obtained copyright permission from the copyright holder to reproduce material in this thesis.
Publications during candidature

Peer reviewed papers

Papers submitted for publication

Presentations

**Publications included in this thesis**

**Incorporated as Chapter 2:**


<table>
<thead>
<tr>
<th>Contributor</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jonathan Redshaw (candidate)</td>
<td>Conceptualised the paper (40%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (70%)</td>
</tr>
<tr>
<td></td>
<td>Edited the paper (50%)</td>
</tr>
<tr>
<td>Thomas Suddendorf</td>
<td>Conceptualised the paper (60%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (30%)</td>
</tr>
<tr>
<td></td>
<td>Edited the paper (50%)</td>
</tr>
</tbody>
</table>

**Note.** Thomas Suddendorf was invited to write the paper with the involvement of colleagues, on the condition that he would remain the first author.

**Incorporated as Chapter 3:**


<table>
<thead>
<tr>
<th>Contributor</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jonathan Redshaw (candidate)</td>
<td>Designed the experiment (90%)</td>
</tr>
<tr>
<td></td>
<td>Performed the experiment (100%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (90%)</td>
</tr>
<tr>
<td></td>
<td>Planned, carried out, and interpreted the statistical analyses (100%)</td>
</tr>
<tr>
<td>Thomas Suddendorf</td>
<td>First used a similar paradigm in a 2011 paper</td>
</tr>
<tr>
<td></td>
<td>Designed the experiment (10%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (10%)</td>
</tr>
<tr>
<td></td>
<td>Edited the paper (100%)</td>
</tr>
</tbody>
</table>
Incorporated as Chapter 4:

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Statement of contribution</th>
</tr>
</thead>
</table>
| Jonathan Redshaw (candidate) | Designed the experiments (90%)     
                            | Performed the experiments (100%)                                                 |
                            | Wrote the paper (90%)                                                                  |
                            | Planned, carried out, and interpreted the statistical analyses (100%)                   |
| Thomas Suddendorf      | Designed the experiments (10%)                                                          |
                            | Wrote the paper (10%)                                                                  |
                            | Edited the paper (100%)                                                                |

Incorporated as Chapter 5:

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Statement of contribution</th>
</tr>
</thead>
</table>
| Jonathan Redshaw (candidate) | Designed the experiment (70%)     
                            | Performed the experiment (100%)                                                 |
                            | Wrote the paper (90%)                                                                  |
                            | Planned, carried out, and interpreted the statistical analyses (100%)                   |
| Thomas Suddendorf      | Designed the experiment (20%)                                                          |
                            | Wrote the paper (10%)                                                                  |
                            | Edited the paper (60%)                                                                 |
| Julie Henry            | Designed the experiment (10%)                                                          |
                            | Edited the paper (40%)                                                                 |
Incorporated as Chapter 6:
Redshaw, J., & Suddendorf, T. (to be submitted). When can preschool children spontaneously prepare for alternative future event outcomes?

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jonathan Redshaw</td>
<td>Designed the experiment (90%)</td>
</tr>
<tr>
<td>(candidate)</td>
<td>Performed the experiment (95%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (90%)</td>
</tr>
<tr>
<td></td>
<td>Planned, carried out, and interpreted the statistical analyses (100%)</td>
</tr>
<tr>
<td>Thomas Suddendorf</td>
<td>Designed the experiment (10%)</td>
</tr>
<tr>
<td></td>
<td>Performed the experiment (5%)</td>
</tr>
<tr>
<td></td>
<td>Wrote the paper (10%)</td>
</tr>
<tr>
<td></td>
<td>Edited the paper (100%)</td>
</tr>
</tbody>
</table>

Incorporated as Chapter 7 (sole author paper):

Note. Thomas Suddendorf offered helpful comments on two early versions of the manuscript.

Contributions by others to the thesis

Several journal editors and anonymous reviewers offered helpful comments on the papers incorporated as Chapters 2, 3, and 7.

Statement of parts of the thesis submitted to qualify for the award of another degree

None.
Acknowledgements

First of all, I must thank my supervisor, Thomas Suddendorf, for his assistance, encouragement, and mentoring throughout the development of this thesis. I deeply admired your courses and writings as an undergraduate student, and it has been an absolute privilege working with you for the past few years. Most of all, I thank you for teaching me how to approach difficult scientific problems with rigor, scepticism and wonder, and to never lose sight of the big picture. I must also thank Julie Henry for her valuable contributions to the study described in Chapter 5, and for her continued mentoring and involvement in follow-up projects. Your enthusiasm for research is utterly infectious and it has been a pleasure working with you.

I additionally acknowledge a number of other people who have offered advice and guidance along the way. In particular, Mark Nielsen, Virginia Slaughter and the UQ Developmental Reading Group, and David Butler and the UQ Evolutionary Reading Group offered useful comments on various aspects of the work presented here. I also thank Melissa Brinums and Emma Prater for their help in data collection with the chimpanzees (and Melissa for scoring some data from the children), and Emily Gibson for her assistance in follow-up projects.

Of course, this thesis would not have been possible without the participants, and so I gratefully acknowledge all of the parents and children who took time out of their daily activities to take part in my studies. On a related note, I must thank the wonderful Sally Clark for going above and beyond in her role at the Early Cognitive Development Centre, and especially for helping out in the warm-up room whenever I ran out of ideas. I also thank Graeme Strachan and Rockhampton Zoo for giving me the opportunity to meet and test the chimpanzees, Cassie, Holly, and Samantha.

Finally, I express deep gratitude to my family for offering much needed support and encouragement throughout the past few years. And I thank all of my friends from various walks, especially the other UQ PhD students with whom I have shared in the ups and downs of postgraduate life.
Keywords

Episodic foresight, mental time travel, planning, episodic memory, information seeking, prospective memory, executive function, metarepresentation, developmental psychology, comparative psychology

Australian and New Zealand Standard Research Classifications (ANZSRC)

ANZSRC code: 170102, Developmental Psychology and Ageing, 85%
ANZSRC code: 170199, Psychology not elsewhere classified, 15%

Fields of Research (FoR) Classification

FoR code: 1701, Psychology, 100%
# Table of Contents

Abstract ................................................................................................................................. ii
Acknowledgements ................................................................................................................ vi
List of Figures and Tables ........................................................................................................ xviii

## Chapter 1: General Introduction ......................................................................................... 1

Introduction ............................................................................................................................ 2
Structure of the Thesis ............................................................................................................ 3
Background and Objective of Chapter 2 (Review) ................................................................. 5
Background and Objective of Chapters 3-6 (Empirical Studies) ............................................ 5
Chapter 3 ............................................................................................................................... 6
Chapter 4 ............................................................................................................................... 7
Chapter 5 ............................................................................................................................... 7
Chapter 6 ............................................................................................................................... 8
Summary ................................................................................................................................. 9
Background and Objective of Chapter 7 (Theoretical Proposal) ............................................. 9

References ............................................................................................................................. 11

## Chapter 2: The Development of Mental Scenario Building and Episodic Foresight .............. 16

Preface .................................................................................................................................... 17
Abstract .................................................................................................................................. 18
Introduction ............................................................................................................................ 19

The Components of Mental Scenario Building ....................................................................... 21

1. The Stage ........................................................................................................................... 22
2. The Playwright ................................................................................................................ 23
3. The Set .............................................................................................................................. 24
4. The Actors ........................................................................................................................ 25
5. The Director ..................................................................................................................... 26
6. The Executive Producer .................................................................................................. 28
# Chapter 7: Does Metarepresentation make Human Mental Time Travel Unique?

**Preface**

**Abstract**

**Introduction**

**Metarepresentation and Mental Time Travel**

**Uncontextualised Representations in Humans and Non-humans**

**Box 1: Mental Space Travel vs. Mental Time Travel**

**Evolutionary Perspective: Uncontextualised Representations vs. Metarepresentation**

**Empirical Concerns**

**A Foresight Equivalent of the False-belief Task?**

**Box 2: ‘Planning’ by Corvids: Metarepresentation or Emotional Cueing?**

**Conclusion**

**References**

---

**Chapter 8: General Discussion**

**Introduction**

**Summary and Extended Discussion of Empirical Findings**

**Chapter 3: Preparing for Deferred Future Episodes**

**Chapter 4: Future-oriented Information Seeking**

**Chapter 5: Time-based Prospective Memory**

**Chapter 6: Preparing for Alternative Futures**

**Age-based Summary and Analysis of Findings**

**Two-year-olds**
Three-year-olds .................................................................................................................. 179
Four-year-olds ................................................................................................................... 180
Five-year-olds .................................................................................................................. 181
Revisiting the Theatre Metaphor ......................................................................................... 182
The Function of Metarepresentational Insight .................................................................... 183
Potential Limitations ........................................................................................................ 185
Conclusion ........................................................................................................................ 186
References ........................................................................................................................ 188
List of Figures and Tables

Chapter 1: General Introduction

Table 1. Summary of the Nature and Participants of Each Body Chapter in the Thesis

Chapter 2: The Development of Mental Scenario Building and Episodic Foresight

Figure 1. Schematic illustration of the components in the theatre metaphor for episodic foresight

Figure 2. Developmental changes in the cognitive components involved in episodic foresight

Chapter 3: Foresight Beyond the Very Next Event: Four-year-olds can Link Past and Deferred Future Episodes

Figure 1. Proportion of 4-year-olds who made the correct item choice in the instant and delayed conditions

Chapter 4: The Development of Future-oriented Information Seeking and Encoding

Figure 1. Representation of test page 1 in the booklet used in Experiments 1A and 1B

Figure 2. Mean test question performance (left panel) and difference scores (right panel) across age groups in Experiment 1A

Figure 3. Mean test question performance (left panel) and critical control question performance (right panel) across age groups in Experiment 1B

Figure 4. Depiction of the Study 2 experimental set-up from the children’s perspective

Figure 5. Mean number of card turns (left panel) and time spent looking at cards (right panel) across age groups and card correctness in Study 2

Table 1. Regression Coefficients for Predictors of Children’s Test Question Performance in Study 2

Chapter 5: The Development of Time-based Prospective Memory in the Presence and Absence of Event-based Cues

Figure 1. Representation of one of the picture sheets used for the prospective memory dual task

Figure 2. Percentage of children from each age group who rang the bell at any time across levels of timer visibility and task load

Figure 3. Cumulative percentage of children from each age group in each accuracy classification group across all four conditions

Chapter 1: General Introduction

Table 1. Summary of the Nature and Participants of Each Body Chapter in the Thesis

Chapter 2: The Development of Mental Scenario Building and Episodic Foresight

Figure 1. Schematic illustration of the components in the theatre metaphor for episodic foresight

Figure 2. Developmental changes in the cognitive components involved in episodic foresight

Chapter 3: Foresight Beyond the Very Next Event: Four-year-olds can Link Past and Deferred Future Episodes

Figure 1. Proportion of 4-year-olds who made the correct item choice in the instant and delayed conditions

Chapter 4: The Development of Future-oriented Information Seeking and Encoding

Figure 1. Representation of test page 1 in the booklet used in Experiments 1A and 1B

Figure 2. Mean test question performance (left panel) and difference scores (right panel) across age groups in Experiment 1A

Figure 3. Mean test question performance (left panel) and critical control question performance (right panel) across age groups in Experiment 1B

Figure 4. Depiction of the Study 2 experimental set-up from the children’s perspective

Figure 5. Mean number of card turns (left panel) and time spent looking at cards (right panel) across age groups and card correctness in Study 2

Table 1. Regression Coefficients for Predictors of Children’s Test Question Performance in Study 2

Chapter 5: The Development of Time-based Prospective Memory in the Presence and Absence of Event-based Cues

Figure 1. Representation of one of the picture sheets used for the prospective memory dual task

Figure 2. Percentage of children from each age group who rang the bell at any time across levels of timer visibility and task load

Figure 3. Cumulative percentage of children from each age group in each accuracy classification group across all four conditions
Table 1. Age-partialed Relationships between Timer Task Data and Executive Function Scores across All Four Conditions ........................................... 112

Chapter 6: When can Children Spontaneously Prepare for Alternative Future Event Outcomes? ........................................................................................................... 119

Figure 1. Depiction of the experimental task given to children and chimpanzees ................................................................. 123

Figure 2. The cumulative number of children from each age group who covered both bottom openings of the pipe for the first time across all twelve trials .................................................................................................................. 124

Figure 3. Grouping of children from each age group according to when and how they used the two-hand strategy across trials ................................................................................................................................. 126

Figure 4. Chimpanzees’ use of the one-hand and two-hand strategies across multiple blocks of twelve trials ................................................................................................................................. 127

Table S1. Gender Split, Mean Age and Standard Deviation of Age for Each Group of Children that Participated in the Experiment ................................................................................................................................. 130

Figure S1. Depictions of the forked and straight tubes used in the experiment ................................................................................................................................. 131

Figure S2. Experimental setting for Cassie ................................................................................................................................. 134

Figure S3. Detailed summary of chimpanzees’ performance across all blocks of trials .......................................................................................................................................................................................... 136

Figure S4. Depiction of Samantha (left) and Holly (right) eventually using the two-hand strategy after many trials of using the one-hand strategy .................................................................................................................................................. 137

Chapter 7: Does Metarepresentation make Human Mental Time Travel Unique? ................................................................................................................................. 141

Figure 1. Illustration of four instantiations of metarepresentation ................................................................................................................................. 148

Figure 2. An alternative, non-metarepresentational explanation for an experiment that appears to show great apes acting for a specific future episode .......................................................................................................................................................................................... 153

Chapter 8: General Discussion ................................................................................................................................................................................................. 166

Figure 1. Representation of the difference between singly and doubly embedded mental time travel .......................................................................................................................................................................................... 171

Figure 2. A modified, computerised version of Chapter 5’s prospective memory paradigm that can be administered to older children and adults .......................................................................................................................................................................................... 175

Figure 3. Representation of the original apparatus used in Chapter 6 alongside two proposed apparatuses .......................................................................................................................................................................................... 177

Table 1. Potential Function of Metarepresentational Insight in Each Theatrical Analogue .......................................................................................................................................................................................... 184
Chapter 1

General Introduction
One of the most remarkable features of human cognition is the ability to embed imagined scenarios within a specific future context and prepare accordingly. This capacity enables us to act in the present to shape future events to our own desire, which may explain much about why humans have been able to dominate the environment and many other species on this planet (Suddendorf & Corballis, 1997). Yet, despite the fact that behaviour can only affect present and future event outcomes, the psychological sciences have traditionally focused on the various forms of memory, rather than future-directed faculties (e.g., Bauer, 2006, 2007; Clayton, Griffiths, Emery, & Dickinson, 2001; Gathercole, 1998; Schacter, 1996; Squire, 1992; Tulving, 2002). Only in recent years has widespread theoretical and empirical attention been given to the capacity to envision specific future events, or ‘episodic foresight’ (e.g., Atance & O’Neill, 2005; Buckner & Carroll, 2007; Klein, 2013a, 2013b; Schacter, Addis, & Buckner, 2007; Suddendorf & Corballis, 2007; Suddendorf & Moore, 2011).

For the purposes of this thesis, episodic foresight is defined as “the capacity to imagine future scenarios and use such imagination to guide current action” (Suddendorf & Moore, 2011, p. 296). It can be described as the future-directed counterpart of episodic memory, and indeed both capacities are considered expressions of the general faculty known as ‘mental time travel’ (Suddendorf & Corballis, 1997). Consistent with this view, one of the most reliable findings across domains is the commonality between imagining past and future events (Schacter et al., 2012; Suddendorf, 2010a). Episodic memory and episodic foresight both engage similar networks in the frontal, temporal and parietal lobes of the brain (Addis, Wong, & Schacter, 2007; Østby et al., 2012; Spreng, Mar, & Kim, 2009; Viard, Desgranges, Eustache, & Piolino, 2012); both capacities are impaired in hippocampus-lesioned amnesiacs (Barba, Cappelletti, Signorini, & Denes, 1997; Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002), older adults (Addis, Wong, & Schacter, 2008), and various clinical populations (e.g., D'Argembeau, Raffard, & Van der Linden, 2008; Lind & Bowler, 2010; Williams et al., 1996); and both capacities appear tightly linked in development, as children who report accurate details about events from yesterday are also more likely to report accurate details about events from tomorrow (Busby & Suddendorf, 2005; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011; Suddendorf, 2010b).

Aside from these well-established links with episodic memory, however, many fundamental questions about the nature and development of episodic foresight remain contentious. For instance, should episodic foresight be considered as a single encapsulated cognitive module, or is it composed of a number of cognitive components? When do children become able to imagine specific future episodes, and when do they become able to apply this capacity to engage in flexible future-oriented behaviour in diverse contexts? Do all future-oriented behaviours become available to children at roughly the same age, or is there a developmental asynchrony owing to different loads?
placed on the underlying cognitive mechanisms? And are any aspects of episodic foresight uniquely human, allowing children to develop certain future-oriented behaviours that remain out of reach for other animals? The aim of my thesis is to go some way towards answering these questions.

**Structure of the Thesis**

Central to my thesis is the overarching theme that episodic foresight is a multifaceted process involving a number of interconnected cognitive components (Suddendorf & Corballis, 2007). In Chapter 2, I review evidence for the development of the proposed components and the future-oriented behaviours they enable in children, while also identifying areas requiring further research. In the following four chapters, I describe empirical studies investigating the emergence of novel future-oriented behaviours in preschoolers, and embed my findings within the broader developmental literature. These behaviours include solving deferred future problems (Chapter 3), seeking information for specific future episodes (Chapter 4), remembering to carry out intended future actions in the presence and absence of external cues (Chapter 5), and preparing for alternative versions of the future (Chapter 6). The study presented in Chapter 6 also includes a preliminary test of three chimpanzees on the same nonverbal task given to the children. In Chapter 7, I build on a discussion point raised by this test and consider one central component of episodic foresight in the context of whether it makes human mental time travel unique. I conclude with a general discussion (Chapter 8) summarising the findings of the empirical studies and discussing them in the context of the componential analysis presented in Chapter 2 and the theoretical proposal outlined in Chapter 7. The nature and participants of the studies in the body chapters (2-7) are summarised in Table 1, and over the following pages I outline the more specific objectives of the thesis with reference to the theoretical, developmental and comparative episodic foresight literatures.
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Nature of Chapter</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>The development of mental scenario building and episodic foresight</td>
<td>Theoretical and empirical review</td>
<td>0-10 year-old children (reviewed only)</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Foresight beyond the very next event: Four-year-old children can link past and deferred future episodes</td>
<td>Empirical study</td>
<td>4-year-old children (N = 24)</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>The development of future-oriented information seeking and encoding</td>
<td>Empirical study</td>
<td>4- and 5-year-old children (N = 76)</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>The development of time-based prospective memory in the presence and absence of event-based cues</td>
<td>Empirical study</td>
<td>3-, 4-, and 5-year-old children (N = 72)</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>When can children spontaneously prepare for alternative future event outcomes?</td>
<td>Empirical study</td>
<td>2-, 2.5-, 3-, 3.5-, and 4-year-old children (N = 90); chimpanzees (N = 3)</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Does metarepresentation make human mental time travel unique?</td>
<td>Theoretical proposal</td>
<td>Non-human animals, children and adults (reviewed only)</td>
</tr>
</tbody>
</table>
Background and Objective of Chapter 2 (Review)

Reviews of the data from various clinical disorders and brain lesion case studies support the view that the episodic system consists of a number of cognitive components working in concert (Klein, 2013c; Klein, German, Cosmides, & Gabriel, 2004). Suddendorf and Corballis (2007) introduced a theatre metaphor to describe the components that might be implicated in episodic foresight, with various cognitive processes analogous to the theatrical roles of stage, playwright, set, actors, director, executive producer, and broadcaster. Together, these components enable a virtual ‘play’ within the mind’s eye. Suddendorf and Corballis discussed this metaphor from the perspective of comparative psychology, with each theatrical analogue examined in light of whether non-human animals display any evidence of possessing the cognitive mechanisms required. And yet, given that animals may lack one or more of these mechanisms, comparative psychology can only go so far as an empirical base for theories regarding the structure and function of episodic foresight in humans. Indeed, it may be just as fruitful to examine when and how the critical components develop in children, and when and how these components support the emergence of future-oriented behaviour in diverse contexts. More practically, the identification of ages at which various components and future-oriented behaviours typically emerge may eventually lead to the formulation of interventions aimed at improving the skills of developmentally delayed children.

Previous reviews of the development of episodic foresight and related concepts have generally focused on the role of self-projection (e.g., Atance & O’Neill, 2005; Hudson, Mayhew, & Prabhakar, 2010) or temporal representations and executive functions (e.g., McCormack & Atance, 2011) in children’s future-oriented behaviour. Such approaches make a valuable contribution to the literature, but they may come at the cost of neglecting the crucial roles played by other components. In Chapter 2 of my thesis, I provide the first comprehensive review of the development of each episodic foresight component identified in Suddendorf and Corballis’ (2007) theatre metaphor, before discussing when and how these components combine to allow various forms of future-oriented behaviour in children. Throughout this review I highlight areas that remain open for research, and in the following four chapters I describe novel empirical studies in some of these domains.

Background and Objective of Chapters 3-6 (Empirical Studies)

In Chapter 2, it becomes clear that many future-oriented behaviours remain entirely unexamined in children. Steps must therefore be taken to devise novel methods that can answer the questions of when and how these behaviours emerge. In each of Chapters 3, 4, 5, and 6, I first identify and discuss a future-oriented behaviour that has been largely neglected by the previous developmental literature. I then describe and implement a methodological innovation aimed at measuring that behaviour in children. The particular future-oriented capacities under consideration
were chosen not just because of the lack of prior research into their development, however, but also because they represent especially important aspects of well-adjusted adult human behaviour. Indeed, it could be said that each of the examined behaviours plays such a crucial role in adult life that a person who did not efficiently acquire them in childhood would be substantially disadvantaged compared to their peers. It is therefore pertinent to identify the ages at which these behaviours typically begin to appear, such that further steps can eventually be taken to ascertain the precise cognitive mechanisms involved and potentially devise interventions aimed at correcting the behaviour of developmentally delayed children. Given Chapter 2’s conceptualisation of episodic foresight as a multifaceted capacity dependent on specific task demands, it was broadly predicted that the various future-oriented behaviours examined would develop at inconsistent ages throughout the preschool years and beyond.

Chapter 3. One future-oriented behaviour that remains unexamined in children is the ability to recall a problem from the past and act to solve that problem for a deferred future episode. Humans often act to secure long-term future benefits, and we rely on our memories for what was required in similar past situations when doing so. When preparing for a trip to the beach, for example, you may recall the last time you went and forgot to take sunscreen, and draw on this recollection to make sure you take some this time. Initially, parents assist children in their preparations for deferred future events, for example when packing their bags with items they will need throughout a day at preschool. Eventually, however, children will have to rely on their own capacity for episodic foresight in such contexts.

Previous studies of children’s future-oriented object selection have involved future problems that were merely hypothetical (Atance & Meltzoff, 2005), occurred almost immediately after the object was selected (Scarff, Gross, Colombo, & Hayne, 2013; Suddendorf, Nielsen, & von Gehlen, 2011), or were marked by temporal terms such as ‘tomorrow’ (Russell, Alexis, & Clayton, 2010), which many young children have great difficulty understanding (Busby Grant & Suddendorf, 2011). In Chapter 3, I adapt the two-room paradigm previously used by Suddendorf and colleagues (2011) and give children the opportunity to solve a problem for five minutes into the future. Four-year-olds are first introduced to a problem with no solution available, before being taken to a second room and distracted for 15 minutes. They are then given a selection of items (one of which can solve the problem) to place into a bucket, which they are to take back to the first room after a familiar 5-minute sand-timer has completed a cycle. The question of interest is whether the children will select the item that can solve the future problem marked by the sand-timer above chance level, just as they did in the original study when the future episode was to occur in the immediate future (‘now’). Acting for a deferred future episode may or may not be more cognitively
demanding than acting for an immediate future episode, and either finding would have important implications for theories regarding the nature of episodic foresight.

Chapter 4. Another important future-oriented behaviour that remains unexamined in children is the ability to selectively seek information that will only be useful in an anticipated future episode. Humans sometimes seek information not because they will receive an immediate benefit, but rather because they expect that information to become useful with time. During schooling, for instance, activities like studying and homework are often aimed at improving outcomes on future tests and other future situations in the real world. Initially at least, children’s information seeking is scaffolded by parents and teachers, such that the children do not necessarily have to consider the future benefits themselves. Children who do consider these benefits, however, may be more efficient in their own future-oriented information seeking practices, and in their ability to apply that information when appropriate.

Previous studies have shown that even infants have a natural preference for certain novel information (Friedman, 1972; Slater, Morison, & Rose, 1984), and 2.5-year-old children are able to seek information to achieve a present goal (Call & Carpenter, 2001). In Chapter 4, I again adapt the two-room paradigm to see when children can apply this capacity to achieve a future goal. Specifically, I give 4- and 5-year-old children the opportunity to recall a past problem from another room and selectively seek information that will solve the problem upon return to the room in the future (Study 1). Nevertheless, because the two-room paradigm places heavy demands on accurate episodic memory, I also develop a novel paradigm aimed at measuring when children can study information for a future test (Study 2). This paradigm has relaxed memory demands because the information search and future problem occur in the same spatial context. The central question in both tasks is whether the children can narrow their search to information that will be relevant in the future, while ignoring structurally similar information that will not be relevant in the future.

Chapter 5. One future-oriented capacity that has received a moderate amount of attention from the developmental literature is ‘prospective memory’. This capacity is broadly defined as the ability to remember to carry out an intended future action given an appropriate event or at an appropriate time (Kvavilashvili, Kyle, & Messer, 2008; McDaniel & Einstein, 2007). Humans often rely on prospective memory in everyday life, for instance when we must remember to buy milk at the shop or get dinner out of the oven at 7:00pm. Such actions can be triggered automatically by an external cue (e.g., seeing the shop or the clock on the oven), but performance is nevertheless greatly enhanced by internal rehearsal of the prospective intention before it must be carried out (McDaniel & Einstein, 2000). Initially, children will rely somewhat on cues (such as parental requests) as reminders to complete intended actions. As they get older, however, they must increasingly rely on their own ability to internally rehearse and implement such intentions.
Considerable research suggests that children become able to carry out intended future actions when cued during the middle preschool years (e.g., Aberle & Kliegel, 2010; Guajardo & Best, 2000; Kliegel & Jäger, 2007; Kvavilashvili, Messer, & Ebdon, 2001). It remains unknown, however, when they become able to carry out such intentions in the absence of reminders. Measures of event-based prospective memory necessarily require environmental cues to signal when the action should be carried out, but even time-based prospective memory measures have almost universally contained such cues in the form of visible clocks or other timing devices. In Chapter 5, I administer 3-, 4-, and 5-year-olds a novel time-based prospective memory paradigm in which the presence or absence of an external cue is varied. The children’s basic task is to remember to ring a bell when a familiar 1-minute sand-timer has completed a cycle. In half of the conditions the timer is visible, such that the children can rely on the passage of sand as an event-based cue when deciding when to ring the bell. In the other conditions, however, the timer is covered, such that there is no external reminder. In some conditions the timer appears as a single task, whereas in others it is embedded within a secondary ongoing task. The central questions are (i) whether the hiding of the event-based cue makes any difference to children’s propensity to perform the future action, and (ii) at what ages children typically become able to interrupt the ongoing task and carry out the intended future action in both the presence and absence of the event-based cue.

Chapter 6. Another future-oriented behaviour that remains largely ignored by the developmental literature is the ability to prepare for multiple potential outcomes of a single undetermined future event. Humans may possess the incredibly useful capacity for episodic foresight, but this is not to say we are able to predict all future events with a high degree of accuracy. One effective way in which we deal with uncertainty about the future is to prepare for alternative, even mutually exclusive possibilities. We may prepare for a pleasant hike in the mountains, for example, but we also carry wet-weather gear and first aid kits in case misfortune strikes. Despite the importance of this capacity to represent and prepare for multiple futures, however, little is known about when and how it develops in children.

The only two previous studies of children’s capacity to prepare for alternative future outcomes have included complex intermediate steps between the preparatory behaviour and the future event, while also relying heavily on language comprehension and unnatural behavioural responses (Beck, Robinson, Carroll, & Apperly, 2006; Robinson, Rowley, Beck, Carroll, & Apperly, 2006). In Chapter 6, I develop a minimalist paradigm that can measure even very young children’s ability to prepare for multiple potential outcomes of a single future event. Specifically, I give 2-4 year-old children the opportunity to catch a ball that is dropped into a forked tube with one opening at the top but two openings at the bottom. The central question is when children can
prepare for both potential outcomes of the single ball-dropping event by covering both bottom openings of the tube in their attempt to catch the ball. Spontaneous preparation for alternative outcomes on the first trial indicates insight into the contingencies of the task and some understanding of future uncertainty, whereas success on later trials might also be achieved through trial-and-error learning.

Summary. Throughout the discussion sections of each empirical chapter, I consider the results obtained and discuss which components of episodic foresight may have been crucial in the implementation of the children’s future-oriented behaviours. I also make suggestions for future studies that could uncover whether differential levels of competence in these components may have been responsible for the specific developmental trajectories observed. I expand on these ideas in the final general discussion (Chapter 8), by revisiting the theatre metaphor described in Chapter 2 and discussing whether any additions or alterations to the components may be required.

Background and Objective of Chapter 7 (Theoretical Proposal)

Developmental psychology has a long history of sharing theoretical concepts and experimental methods with comparative psychology (e.g., compare Call & Tomasello, 1999; Premack & Woodruff, 1978; Wimmer & Perner, 1983). Indeed, much of the early focus of the developmental episodic foresight literature was on the need to devise nonverbal testing methods, not only to avoid the pitfalls associated with young children’s language deficits but also to allow for testing of non-human animals (Suddendorf & Busby, 2005). While the bulk of my thesis is focused on children’s episodic foresight, I also make a novel theoretical contribution to the comparative literature in Chapter 7. This contribution again falls under the framework of the theatre metaphor outlined in Chapter 2, while also enhancing the interpretation of the empirical findings presented in Chapter 6.

Suddendorf and Corballis laid out the first systematic treatise on mental time travel across species in 1997, proposing that the capacity was unique to humans among extant animals and that episodic foresight in particular was a prime mover in hominin evolution. Since then, a multitude of studies have claimed to provide behavioural evidence for the capacity in non-human animals (e.g., Cheke & Clayton, 2012; Correia, Dickinson, & Clayton, 2007; Naqshbandi & Roberts, 2006; Raby, Alexis, Dickinson, & Clayton, 2007), with special attention given to the future-directed faculties of humans’ closest living great ape relatives (Mulcahy & Call, 2006; Osvath, 2009; Osvath & Karvonen, 2012; Osvath & Osvath, 2008). Suddendorf and Corballis responded to these initial claims with scepticism, suggesting that the evidence could all be explained by more parsimonious mechanisms such as associative learning or instinctual predispositions (Suddendorf, 2006; Suddendorf & Corballis, 2007; Suddendorf & Corballis, 2008; Suddendorf, Corballis, & Collier-Baker, 2009). In recent years, however, Corballis has changed his mind (Corballis, 2013a, 2013b,
2013c, 2014), on the basis of neurological evidence suggesting that rodents mentally represent novel maze trajectories and then are more likely to take these paths in the future (e.g., Gupta, van der Meer, Touretzky, & Redish, 2010; Pastalkova, Itskov, Amarasingham, & Buzsáki, 2008; Pfeiffer & Foster, 2013). He now believes the difference between human and non-human mental time travel to be quantitative only, rather than qualitative.

In Chapter 6 of my thesis (described above), I include a preliminary test of three chimpanzees’ ability to prepare for multiple versions of an immediate future event, using the same paradigm administered to the child participants. In Chapter 7, I build on a question raised in the discussion section of Chapter 6, and suggest that there may indeed be something unique about human mental time travel. Specifically, I suggest that non-human animals may lack the capacity to form metarepresentations, which allows humans to reflect on the relationship between their mental representation of a given event and the event itself (Perner, 1991; Pylyshyn, 1978; Suddendorf, 1999). Without this component, an agent cannot embed their representations within a certain representational context (e.g., the future) or understand that such representations can be misleading. I describe how the aforementioned neurological evidence from rodents and behavioural evidence from other animals can be explained without necessarily ascribing these animals a capacity for metarepresentational insight. Finally, I suggest how empirical progress might be made on this problem, including a recommendation that future research test animals on paradigms such as the one described in Chapter 6. I return to the issue of metarepresentation in the general discussion (Chapter 8), in which I propose an expanded, overarching role for the capacity in all components of the theatre metaphor of episodic foresight.
References


Cheke, L. G., & Clayton, N. S. (2012). Eurasian jays (Garrulus glandarius) overcome their current desires to anticipate two distinct future needs and plan for them appropriately. *Biology Letters, 8*(2), 171-175.


Chapter 2

The Development of Mental Scenario Building and Episodic Foresight
Preface

Having given a general introduction to the relevant literature in the previous chapter, I now move onto the main body section of my thesis. I begin by reviewing evidence for the development of various cognitive components of episodic foresight and the future-oriented behaviours they enable. This chapter is an adapted version of a review article\(^1\) published with my supervisor, Thomas Suddendorf. He was invited to write the article with colleagues, on the condition that he remain the first author. It was his idea to frame the paper in the context of the theatre metaphor of episodic foresight (Suddendorf & Corballis, 2007), although the first draft was written by me (including initial versions of both figures and many of the novel ideas). We retained all sections of this initial draft and edited the paper together to produce the final version.

Abstract
Episodic foresight is the future-directed counterpart of episodic memory. It is a sophisticated, potentially uniquely human capacity, with tremendous adaptive consequences. Here we review what is currently known about its development through early childhood. We tackle this from two distinct perspectives. First, we present the first systematic evaluation of the development of purported components of mental scenario building as highlighted by a theatre metaphor: the stage, the playwright, the set, the actors, the director, the executive producer and the broadcaster. We find that, although there are diverse developmental trajectories, by four years of age children have acquired the basic cognitive components required to mentally construct specific future events. Second, we examine recent attempts to test children’s episodic foresight more directly and find that results are in line with those examining the development of required components. This is not to say that children younger than four have no inkling of upcoming events, or that older children have nothing left to learn about constructing the future. Episodic foresight, and its neurocognitive foundations, continues to develop throughout childhood.
The idea of a central Cartesian theatre in the brain has been rightly criticised (Dennett & Kinsbourne, 1992). Yet, the wholesale rejection of this idea should not obscure the fact that humans can envisage scenarios in their minds, however those may be instantiated in the brain. We can build mental scenarios, communicate them and act them out. Over the last half dozen years cognitive and neuroscientific studies have (finally) begun to pay special attention to our capacity to imagine future situations (Bar, 2011; Schacter, Addis, & Buckner, 2008; Suddendorf & Corballis, 2007), which has arguably given humans crucial adaptive advantages over other animals (Suddendorf, 2006; Suddendorf & Corballis, 1997). As adults, this faculty allows us to act with foresight, to prudently prepare for threats and opportunities, to hatch complex plans, and to design much of our world aiming at what we think we would like. For most problems, we can generate multiple scenarios of potential solutions, evaluate them in terms of likelihood and desirability, and decide to pursue one of these options with an apparent sense of free will. Young children, however, require adults to structure and support their future-oriented behaviour (Hudson, 2002). Here we review the growing literature on the development of their ability to imagine and shape the future in their own right.

Like other sub-disciplines in the behavioural and cognitive sciences, developmental psychology has long overlooked foresight in favour of research on memory (Bauer, 2007; Fivush, 2011; Hayne & Rovee-Collier, 1995; Nelson & Fivush, 2004). Yet, from an evolutionary perspective, cognitions about the present and the future are much more important than representations of the past per se. Natural selection can only work on how a cognitive capacity affects an organism’s present and future survival or reproductive chances (Suddendorf & Busby, 2003). It has even been suggested that episodic memory evolved as an adaptive design feature of the capacity for episodic foresight (Suddendorf & Busby, 2005), a proposal supported by neuroscientific evidence suggesting that both capacities activate similar brain regions (Addis, Wong, & Schacter, 2007; Botzung, Denkova, & Manning, 2008; Okuda et al., 2003; Spreng, Mar, & Kim, 2009; Szpunar, Watson, & McDermott, 2007) and impairment in one is associated with impairment in the other (D'Argembeau, Raffard, & Van der Linden, 2008; Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002; Rosenbaum, Gilboa, Levine, Winocur, & Moscovitch, 2009). In many contexts the past is the best predictor for the future. Therefore, memory of a past event can offer useful guidance as to what to expect in a similar future event. However, we can do a lot more. The future is uncertain and regularly dishes up situations that are entirely novel. There is debate regarding just how episodic foresight contributes to future-oriented behaviour (Corballis, 2013a, 2013b; Eacott & Easton, 2012; Klein, 2013; Suddendorf, 2013), but it is clear that representing novel future events requires more than just a system that projects the past into the future (Gilbert & Wilson, 2007; Suddendorf & Busby, 2003).
We can imagine whatever, wherever, whenever by recombining basic elements, such as actors, objects and actions, in novel ways, just as we can generate new sentences from words or melodies from tones (Suddendorf & Busby, 2003). Consider the following brief example. Imagine you remember giving a lemon cheesecake to a friend and confidently predict that if you did it again he would be just as delighted as on the previous occasion. To illustrate that you can also imagine things that have not happened before, let’s imagine you entertain the idea of putting hot English mustard on the cake. Without ever having tasted this before, you can quite confidently predict that the combined flavour would be awful. You can go on and picture the reaction that taste would draw from our friend, and the repercussion this would have, for instance, in terms of retaliation. You may attempt to recruit someone else as a partner in crime, but she may not be compelled, pointing out the consequences this prank would have on your reputation amongst your friends. And so, while you might briefly entertain the mischievous idea, perhaps while recognising the similar colours of lemon icing and mustard, you would probably select to refrain from such a naughty deed.

We frequently consider potential future scenarios and act, or refrain to act, with anticipated future consequences in mind. We often get it wrong, of course. But foresight has been a tremendous survival tool. We pursue short and longer-term goals, shape the future to our design, recognise opportunities and prepare for the worst. Our actions reflect our thoughts about temporally displaced events, be they next week’s work commitments, this summer’s holiday or one’s retirement plan. Much of our adult thinking depends on episodic foresight. Yet, infants very much live in the here and now and even young children display few obvious signs of prudently plotting the future, instead relying on adults to imagine and structure their future activities. We pack their lunches, bring their jackets and schedule their play dates. An important task for developmental psychology, then, is to identify and explain the development of episodic foresight (Suddendorf & Moore, 2011).

Current neuroscientific data (Addis & Schacter, 2008; Andelman, Hoofien, Goldberg, Aizenstein, & Neufeld, 2010; Irish, Addis, Hodges, & Piguet, 2012a, 2012b; Weiler, Suchan, Koch, Schwarz, & Daum, 2011) support the notion that episodic foresight is more than just episodic memory placed into the future—it also requires the ability to recombine episodic elements into novel constellations (Addis & Schacter, 2012; Schacter et al., 2012; Suddendorf, 2010a). However, episodic memory and detail recombination are not the only components driving successful future-oriented behaviour. Instead, episodic foresight often critically depends on various sophisticated cognitive skills, such as: placing the episode at a specific time in the future; thinking about one’s own and others’ future minds; judging the future episode on dimensions such as likelihood and desirability and altering it accordingly; inhibiting immediate impulses so that the future episode can be envisioned and actualised; and discussing the future episode with others. In the following
sections we review recent research on (i) the development of cognitive components implicated in episodic foresight, and (ii) the development of future-oriented behaviours that these components support. Our suggestions for future research include open questions within these two domains, as well as a discussion of how findings from developmental psychology can guide searches for the neural underpinnings of episodic foresight.

The Components of Mental Scenario Building

Suddendorf and Corballis proposed the metaphor of a theatre production to help identify the diverse cognitive components involved in episodic foresight (Suddendorf & Corballis, 2007). Here we review what is known about the development of cognitive analogues of the stage, playwright, set, actors, director, producer and broadcaster (see Figure 1). We are, of course, not making the case for some homunculi performing such tasks nor for any Cartesian theatre in the mind/brain (Dennett & Kinsbourne, 1992). The components may well depend on widely distributed, interconnected and parallel processes. The theatre metaphor was originally advanced in the context of evaluating whether nonhuman animals might have the cognitive capacities required to travel mentally in time (as shortcomings in one or several of the components may significantly limit their foresight). Here we adopt this approach to systematically examine when children acquire competence in these purported components. We then compare the findings of this indirect approach with a review of research aimed at directly measuring the development of episodic foresight and future-oriented behaviour. We find that, by four years of age, human children have all of the basic cognitive components required to mentally construct specific future events. This is not to say, however, that younger children have no inkling of upcoming events, or that older children have nothing left to learn about constructing the future. The components mature along different trajectories and episodic foresight capacities continue to develop throughout childhood.
Figure 1. Schematic illustration of the components in the theatre metaphor for episodic foresight. The executive producer can override online processes and engage offline scenario building. The playwright fills representational space (the stage) with set features and actors and generates simulated interactions. The director judges the mental construction on dimensions such as likelihood and desirability, and either (1) rejects the scenario and sends it back to the playwright for modification, or (2) accepts it and passes it on to the executive producer. This evaluation can be assisted by an audience, if the director broadcasts the anticipated future scenario and receives feedback in return. The executive makes the final decision on any implementation of an action plan.

1. The Stage

The first component required for any successful theatre production is a stage on which reality can be suspended for the duration of the show. Similarly, in order to mentally construct potential future events, we require a virtual space in our minds able to entertain offline representations. In addition to perceiving a lemon cheesecake, we need to be able to imagine something that is not there, such as a layer of mustard. By 18 months of age, children show some basic capacity to go beyond immediate perception to entertain alternative states of the world through pretend play (Fein, 1981). Toddlers start to bring to mind offline representations and exert some top-down control over them. So a stick becomes a doll or a gun, and toddlers do not mistake one for the other. They actively imbue the real object with pretend characteristics, keeping in mind two models of the world, the pretend and the real (Perner, 1991; Suddendorf & Whiten, 2001). This is not to say, however, that mental object substitution implies that toddlers can construct and
compare multiple scenarios as typically required for effective episodic foresight (Harris, 2000; D. M. Peterson & Riggs, 1999). Only from around ages three to four do children show signs of counterfactual thinking, allowing them to contrast an event that did happen with a similar event that did not happen (Harris, German, & Mills, 1996), and some data point to an even later time of emergence (Rafetseder, Cristi-Vargas, & Perner, 2010; Rafetseder & Perner, 2010).

Working memory is typically considered to be the mental stage where such offline representations are temporarily combined and manipulated (Baddeley, 1992). And indeed, working memory storage capacity increases throughout childhood and adolescence (Gathercole, Pickering, Ambridge, & Wearing, 2004). In a monumental study involving 709 children, Alloway and colleagues (2006) tested the development of working memory capacity with a number of tasks, documenting linear increases from ages four to eleven. Though it is tempting to conceptualise working memory capacity as merely the quantitative limit of the qualitative ability to represent offline material, this may not be the entire story. An increase of only one chunk in working memory could herald the emergence of an entire range of qualitatively distinct cognitive operations (Read, 2008; Suddendorf, 2013). Limits to the number of items and relations that can be entertained have been proposed to explain fundamental differences between humans and nonhuman animals and between the cognitive capacities of different age groups (Balter, 2010; Halford, Wilson, & Phillips, 1998). Note, however, that a correlational study of three to four-year-olds failed to find an association between working memory capacity and counterfactual reasoning (Beck, Riggs, & Gorniak, 2009).

2. The Playwright

A theatre production requires a playwright providing the narrative and mental scenarios too may require some kind of script. Humans have top-down access to a database of elements for such a script in declarative memory, which comprises both semantic and episodic memory (Squire, 1992). The early development of declarative memory in non-verbal infants has traditionally been assessed through deferred imitation (Meltzoff, 1988), an ability sometimes impaired in adult amnesia (McDonough, Mandler, McKee, & Squire, 1995). By six months of age, children can imitate a novel action they were first exposed to 24 hours earlier, and over the subsequent year imitation over greater delays becomes evident (Barr, Dowden, & Hayne, 1996; Barr, Vieira, & Rovee-Collier, 2001; Jones & Herbert, 2006). Though deferred imitation may require semantic memory, however, it need not require mental revisiting of the initial learning episode (Clayton & Russell, 2009). Unequivocal evidence for episodic memory appears only around age 3 to 4 (Scarff, Gross, Colombo, & Hayne, 2013; Suddendorf, Nielsen, & von Gehlen, 2011), although some authors have made the case for earlier developments (Bauer & Dow, 1994; Bauer & Leventon, 2013). Accumulation of information in both declarative memory systems over the life span offers
an increasingly rich database—also referred to as crystallised intelligence (Horn & Cattell, 1967)—from which to construct future episodes.

We have seen earlier that recurring events may be predicted by simply redescribing the representation of a past event as a future event, and declarative memory may be crucial for this process. But to imagine novel future constellations, such as mustard on cheesecake, we must also be able to combine and recombine declarative elements in flexible ways. Suddendorf and Corballis have argued that such open-ended generativity to plot whatever, wherever, whenever is achieved through recursive rules (Corballis, 2011; Suddendorf & Corballis, 1997, 2007). Recursion, or the ability to embed concepts within similar concepts, allows humans to generate a virtually infinite number of scenarios from a finite set of elements from memory, just as we can recursively combine words into sentences (Chomsky, 1966; Hauser, Chomsky, & Fitch, 2002). Although recursive grammar, in the broadest sense, appears during the third year, it is only during the fourth year that English-speaking children begin to embed clauses within other clauses (Owens, 2008; Wells, 1985). From around this age children also become increasingly capable of generating multiple solutions to the same problem and predicting what might happen tomorrow (Claxton, Pannells, & Rhoads, 2005; Suddendorf, 2010b; Suddendorf & Fletcher-Flinn, 1999; Urban, 1991).

3. The Set

In order to imagine a realistic future episode, one may need some basic appreciation of the physical laws that govern relations between objects in the environment. Several lines of research have demonstrated that infants begin to grasp some of the basic principles of physical causality during the first year of life (Baillargeon, 2002; Leslie & Keeble, 1987; Spelke, Phillips, & Woodward, 1995). The crucial dimension for our purposes, however, is time. By four years of age, many children can correctly distinguish between daily future events such as next dinner and distant future events such as driving a car, by appropriately placing these events on a visual timeline (Busby Grant & Suddendorf, 2009). Only by five, however, can children distinguish between annual and distant future events (Busby Grant & Suddendorf, 2009), and plan an intervention for an early time that will help a character instead of planning it for a later time that will not help the character (McColgan & McCormack, 2008; McCormack & Hanley, 2011). And until around six, many children mistakenly believe that annual events from the recent past (e.g., a Christmas or Valentine’s Day that occurred a week ago) will occur again in the near future (Friedman, 2003; Friedman & Kemp, 1998), suggesting that younger children may fail to grasp at least some important differences between the past and future (Friedman, 2008).

The ability to place future events appropriately in time may be facilitated by an understanding of cultural time patterns such as days of the week and months of the year. English speaking children acquire the names of days by around age seven, and the names of months by
around age nine (Friedman, 1986, 2005). However, they can reliably judge temporal distances between days only by about age nine, and between months only by about age 11 (Friedman, 1986, 2005). Surprisingly little is known about the development of children’s understanding of seconds, minutes, and hours. In a survey, fewer than half of 5-year-olds’ parents reported that their children used ‘minutes’ or ‘hours’ correctly (Busby & Suddendorf, 2011), and so development appears to continue throughout middle childhood. Temporal concepts are cultural heritage that help in the conceptualisation of the time dimension and in the coordination of future-directed activities. Without them, children’s planning and thinking about the future may be severely limited. Unfortunately, it remains unclear what formative role cultural time concepts have on children’s thinking. We are not aware of cross-cultural developmental data from societies that have different systems of reckoning time and perhaps different emphasis on matters temporal. It remains to be seen what is universal about these developments.

4. The Actors

In order to successfully predict future events involving self and others, children need to understand the relationship between their current and future self, and may require some understanding of why people behave in the way they do (Suddendorf & Corballis, 1997). The most common developmental test for early self-awareness is the mark test for mirror self-recognition, even if its interpretation is debated (Amsterdam, 1972; Gallup, 1970, 1997; Heyes, 1994; Suddendorf & Butler, 2013). Children reliably recognise themselves in mirrors by the end of the second year (Asendorpf & Baudonniere, 1993; Lewis & Ramsay, 2004; Nielsen & Dissanayake, 2001). However, it is identification with one’s future self that is critically important for episodic foresight, as one needs to care about one’s future in order to motivate current actions aimed at securing future well-being or preventing future harm (Lemmon & Moore, 2001; Moore & Lemmon, 2001). The mark test has been adapted in attempts to measure a temporally extended sense of self by presenting children with delayed video images (Povinelli, Landau, & Perilloux, 1996). Only from around age 4 do children retrieve a sticker from their head after seeing themselves marked in a 3 minute old video (Povinelli, et al., 1996; Suddendorf, 1999a; Zelazo, Sommerville, & Nichols, 1999). Unfortunately, there are numerous methodological and theoretical problems with the ‘temporally extended self’ interpretation of task performance (Povinelli & Simon, 1998; Suddendorf, 1999a). One problem with these delay studies is the baseline. Self-recognition in live video, even when matched to mirrors in terms of reversal and image size, appears to emerge about year later than self-recognition in mirrors (Suddendorf, Simcock, & Nielsen, 2007). Whether the task measures self-awareness in any sense other than an expectation about one’s appearance in a medium remains debated (Butler, Mattingley, Cunnington, & Suddendorf, 2012).
Mental time travel has long been argued to draw on the same cognitive resources as theory of mind (Suddendorf & Corballis, 1997). Indeed, several authors have pointed out various ways in which theory of mind and episodic foresight might be linked (see Moore & Lemmon, 2001). It would seem likely, for instance, that representing the content of other minds involves many of the same mechanisms as representing the content of one’s own future mind. The development of false-belief understanding has drawn particular attention in the theory of mind domain because it shows an appreciation that others act on their representations of the world, whether these are correct or not. Such understanding hence demonstrates a capacity for representing representational relations—or metarepresentation. The acquisition of this capacity around age 3 to 4 is often regarded as a qualitative developmental shift with wide-ranging consequences (Perner, 1991; Suddendorf, 1999b; Wellman, Cross, & Watson, 2001), but note that there is some controversial evidence for much earlier (implicit) false-belief understanding (Buttelmann, Carpenter, & Tomasello, 2009; Low & Perner, 2012; Onishi & Baillargeon, 2005; Perner & Ruffman, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007). This capacity is necessary to appreciate how minds, including one’s own, may change depending on future events (Suddendorf & Corballis, 1997). When children pass classic false-belief tasks, they also begin to demonstrate a range of other abilities useful for future planning, such as an understanding that appearances (like lemon-iced cakes) sometimes do not match reality (Gopnik & Astington, 1988), that they have not always known facts that they know now (Gopnik & Graf, 1988), and that there is a tight link between perception and knowledge (Perner & Ruffman, 1995). Indeed, a recent study found a positive relationship between preschoolers’ performances on a verbal false-belief task and a task that required them to learn a rule that had to be applied in the future (Ford, Driscoll, Shum, & Macaulay, 2012). More sophisticated theory of mind abilities, such as understanding hidden emotions (Wellman, Fang, & Peterson, 2011) and sarcasm (C. C. Peterson, Wellman, & Slaughter, 2012), develop later—and arguably we never quite stop learning about the workings of minds. Predicting one’s own and others’ future mental states is often critical for accurate anticipation of important future events.

5. The Director

After receiving the script from the playwright, the director of a theatre production might try out multiple ways of playing out a scene before deciding on the best one. The future is uncertain and so it may often be useful to generate multiple potential scenarios (e.g., is it going to be mustard or lemon icing?) and evaluate them in terms of their likelihood and desirability. We can direct out mental scenarios and adjust details of the anticipated event, or even imagine a completely novel narrative (e.g., forget the cake and buy some champagne instead). This ability to generate and
select—to choose one path amongst several potentials we are aware of—is crucial for flexible foresight. It gives us an intuitive belief in “free will” (Alexander, 1989).

A fundamental problem for such a foresightful system of decision making is how to come to an adaptive decision point. Our open-ended generativity could in principle allow us to keep producing new versions of future events and become hamstrung by indecision—as indeed sometimes we are. Consider the following recursive procedure, which includes the option for an infinite foresight loop or a termination when necessary:

1. Imagine a novel future scenario and evaluate its probability and desirability.
2. Is the future outcome likely enough and desirable enough?
   a. No—repeat step 1 [recursion].
   b. Yes—pursue the imagined course of action to bring about this outcome.

The procedure can be looped until an acceptable level of desirability and likelihood has been reached. Research on decision making shows that humans often do not follow optimal, rational rules, but instead come to a decision as soon as an acceptability threshold is reached—what Herbert Simon (1956) called satisficing. Such an approach may not be optimal if compared to reason with unlimited time and computational resources, but it is immensely practical. In fact, we argue it is crucial for a system that bases decisions on individual mental scenario building. A satisficing termination frees the system to focus on the next task, as soon as possible, rather than endlessly trawling all possible versions of future events. The development of this important ability has, as far as we know, not been studied yet.

Reasoning about alternative events, however, has been examined. For instance, as described in the stage section, children become able to answer counterfactual questions about past events around age 3 (German & Nichols, 2003; Perner, Sprung, & Steinkogler, 2004). When told a story about a character who walks on a clean carpet with dirty shoes, 3-year-olds understand the floor would have remained clean if the character had taken her shoes off first (Harris, et al., 1996). Such stories, however, merely require the ability to reason about a different event to the one that actually occurred. They do not require the child to represent multiple potential outcomes for the same event (Beck, Riggs, & Gorniak, 2010). In order to differentiate between these abilities, Beck and colleagues (2006) gave children a problem in which a toy mouse could emerge at the bottom of one of two slides. When told they could place mats at the bottom of the slides to protect the mouse, only 30% of 4-year-olds placed mats at the bottom of both slides, even when prompted with the question “could he go anywhere else?” after placing a single mat. On the other hand, these 4-year-olds performed near ceiling level when asked a simple counterfactual question after the event: “what if next time he goes the other way?” Only by five did the majority of children place two mats
in the undetermined future task, suggesting that they possessed the ability to compare and contrast multiple possible versions of a single future event.

Often we do not direct very realistic mental scenarios. We may imagine only what we desire and frequently expect that positive events are far more likely to occur than one could rationally expect (Weinstein, 1980). In fact, humans demonstrate various systematic biases when predicting the future (Gilbert & Wilson, 2007; Tversky & Kahneman, 1974). For example, we tend to underestimate the time it will take to complete a goal (Buehler, Griffin, & Ross, 1994) and overestimate the sadness at not achieving the goal (Wilson & Gilbert, 2005). These foresight biases may be functional adaptations, as they increase a person’s motivation to pursue future goals (Buehler, et al., 1994; Suddendorf, 2011). We do not know of any studies on affective forecasting biases in children, though they certainly take immense pleasure in anticipated events, such as an upcoming birthday or Christmas. Lagatutta and Safyan (2011) gave children and adults pictures of simple ongoing events and asked them to estimate the likelihood of a specific future outcome—for example, how likely it was that a giraffe of a given height would be able to reach a piece of food. Understanding of likelihood and uncertainty improved significantly from 4-5 to 6-7, and from 6-7 to 8-10. Children spend a lot of time in fantasy play, acting out scenarios and affective reactions. These activities, coupled with actual real life experiences, may be essential in enabling better assessment of imagined potential future scenarios.

6. The Executive Producer

A successful theatre production requires an executive producer able to oversee the practical and fiscal aspects of the project and, ultimately, put the play into action. Similarly, to act prudently with the future in mind may require some executive function. In general, executive function covers the range of psychological mechanisms that allow organisation of action in relation to competing sources of information, as well as the flexible shifting of action choice in response to changes in information (Garon, Bryson, & Smith, 2008). Executive function is implicated in the development of basic forms of planning (McCormack & Atance, 2011), such as that required by Tower of London tasks (Bull, Espy, & Senn, 2004), but it may be just as important for planning future events that are entirely removed from the here-and-now (Suddendorf & Corballis, 2007). In situations where achieving a future goal requires only a single current action, the most important executive ability is inhibition. Specifically, one must be able to implement an action that is more effortful in the face of a competing action that is more automatic; and/or to respond to information of less salience (e.g., only represented in imagination) in the face of information of greater salience (e.g., presented perceptually). For more complex future goals, one must also be able to flexibly shift focus from one aspect of the problem to another when required (P. Anderson, 2002; Suddendorf & Corballis, 2007).
Infants begin to show basic forms of inhibition, in which they must withhold an automatic response, late during the first year and early during the second year of life (Diamond, 1990; Kochanska, Tjebkes, & Fortnan, 1998; Scerif, Cornish, Wilding, Driver, & Karmiloff-Smith, 2004). But young children often persevere and fail to executively control their action intelligently. For example, although 24-month olds can use a picture to find a hidden object in a room on their first trial, on subsequent trials they tend to simply return to the location of previous success rather than to where the object is indicated on the photo (Suddendorf, 2003). Beyond this age children become increasingly competent in their executive control. The wait-based delay of gratification task, for example, requires a child to wait until an absent experimenter returns with a large reward, or ring a bell and have the experimenter immediately return with a smaller reward (Mischel, Shoda, & Rodriguez, 1989). Between two and four years of age, there is a gradual improvement in the length of time children are able to wait, with the majority of 4-year-olds able to wait at least five minutes (Kochanska, Murray, & Harlan, 2000; Kochanska, et al., 1998). The children who demonstrate more control have various advantages later in life (Shoda, Mischel, & Peake, 1990).

Munakata and colleagues (2012) identify three transitions in control: (i) from perseveration to responding based on external signals, (ii) from re-active control to pro-active control and (iii) from environmental triggers to autocuing. By about age 4 children begin to demonstrate some capacity to follow a rule even when it contradicts some prepotent response. Unlike 3-year-olds, for example, 4-year-olds can respond appropriately to Stroop-like tasks (Espy, 1997; Gerstadt, Hong, & Diamond, 1994), follow rules to do as another says even if it conflicts with what the other does (Diamond & Taylor, 1996), select a small over a large reward after repeatedly experiencing that this is the more beneficial choice (Carlson, Davis, & Leach, 2005), and sort multidimensional cards first by shape and then by colour (Zelazo, Müller, Frye, & Marcovich, 2003). However, 4-year-olds’ initially successful performances on some of these tasks can deteriorate to chance level over very short time periods (Diamond & Taylor, 1996; Gerstadt, et al., 1994), suggesting that young children’s executive resources are rather limited. Indeed, the ability to follow counterintuitive rules continues to develop throughout childhood and well into adolescence and young adulthood (V. Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Bedard et al., 2002; Davidson, Amso, Anderson, & Diamond, 2006; Kalkut, Han, Lansing, Holdnack, & Delis, 2009; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). This late development means children may often struggle to implement actions aimed at imagined future goals.

7. The Broadcaster

Although episodic foresight can be immensely powerful and flexible, it is also a dangerously risky way of making decisions. We are not clairvoyants and our imagined future events may be wide off the mark. A major way in which we improve the accuracy of our future scenarios is by
broadcasting them to each other. People who have been in the situation before can offer the best advice about what to expect from the future episode (Gilbert, 2006). By telling others what we think will happen or what we plan to do, we can solicit feedback, comments and advice. This can dramatically reduce error rates. A friend’s advice to not put mustard on the cheesecake may save you, not to mention the target, a lot of grief. Language may have evolved in part to communicate mental scenarios about past and future (Suddendorf, Addis, & Corballis, 2009). These exchanges also allow us to coordinate our actions in novel ways. Negotiation of shared plans allows members of a cooperative group to adopt specific roles within an agreed future event. Children frequently negotiate their roles in play and this may allow them to practice such collaborations for more serious circumstances.

Future-oriented talk requires specific linguistic markers. With the correct use of future tense, for example, children are able to ensure their audience understands the described event is located in the future rather than the past. Similarly, with the correct use of terms such as ‘before’ and ‘after’, children are able to describe sequential relationships between sub-events located within the imagined future episode as a whole. Although some temporal markers appear relatively early in language development (Clark, 1971; Veneziano & Sinclair, 1995), it is only between the ages of three and seven that significant improvements are seen in the correct use of many indicators of time (Busby & Suddendorf, 2011; Harner, 1980; Stevenson & Pollitt, 1987).

Perhaps the most important capacity required for the effective communication of future event plans is an understanding of narrative structure. By using this structure, we can provide setting information, background information and sequential information about the central future event and thus optimise the chance that the audience will construct a matching event within their own virtual theatre(s). Both past and future narratives tend to have important social functions, and note that recent research on self-reports suggests that future narratives are more relevant than past narratives to one’s life story and identity (Berntsen & Bohn, 2010). Children first experience narratives via conversations about the past and future with their parents, and there is evidence that parents who provide more elaborative narratives have children who produce more detailed linguistic constructions of the past (Fivush, 2011) and the future (Hudson, 2006)—although note that cultures may differ in how much detail people typically provide (Wang, Hou, Tang, & Wiprovnick, 2011). Children begin to spontaneously produce their own narratives centred on general event scripts between age two to three (Fivush & Slackman, 1986; Hudson, Shapiro, & Sosa, 1995; Nelson & Fivush, 2004), and by five their narratives about future events include strategies aimed at preventing negative outcomes (Hudson, et al., 1995). Only by nine, however, do the majority of children include setting information, background information, sequential information and a climax in their personal narratives (Hudson & Shapiro, 1991). Without these elements, young children may
struggle to elicit a closely matching future event representation in the audience. Consequently, children may not give nor receive the best possible advice about how to approach a future event.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretend play</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playwright</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recursive embedding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declarative memory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal event placement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural time concepts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual self-recognition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of mind</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Director</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative futures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood of future events</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Executive producer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhibit automatic response</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex inhibition, set-shifting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadcaster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General temporal language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrative structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2.* Approximate representation of developmental changes in the cognitive components implicated in episodic foresight (darker shades of grey represent increasing competence).

**Summary**

As summarised in Figure 2, the development of components purportedly involved in episodic foresight is diverse, with certain milestones occurring well before others. While some components such as working memory capacity appear to develop gradually throughout childhood, others, such as self-recognition, change rapidly around specific time periods. There may thus be qualitative and quantitative transitions with different effects on the development of episodic foresight. Still, it is important to note that many experimental approaches focus on establishing competence at certain ages rather than demonstrating absence of capacities. As failures to perform can be due to many reasons other than the one of interest, the evidence may well underestimate
capacities of younger cohorts. As it stands, the available evidence suggests that, while some components begin to emerge by the second year of life, it is only by the end of the third year that developments in all components are documented. This pattern is consistent with the evidence from recent studies attempting to assess the development of episodic foresight more directly. To those, we shall turn next.

**The Development of Foresightful Behaviour**

Planning is traditionally studied with problems such as the Tower of London (Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008) or route-planning games (Gauvain & Rogoff, 1989). However, these approaches do not require children to think beyond a single, ongoing, immediate context and therefore arguably do not require episodic foresight (Hudson, Mayhew, & Prabhakar, 2011). The easiest way to examine children’s access to more removed events is to question them. A number of studies have asked children to report specific events that will happen ‘tomorrow’ (Busby & Suddendorf, 2005; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011; Suddendorf, 2010b). Results indicate that, while 3-year-olds can report some events, 4- and 5-year-olds report more total events and more events judged by parents as correct. Similarly, when asked to describe plans for hypothetical future events, older preschoolers tend to provide more details than 3-year-olds (Hudson, et al., 1995), consistent with the developments of the episodic foresight components reviewed earlier. Because young children are in the process of learning temporal language, however, there are two fundamental problems with this direct approach. First, they may understand something and yet do not have the language to broadcast their capacity. Second, they may use words appropriately and yet not quite understand (Lyon & Flavell, 1994). Given these problems with false negatives and false positives, studies examining future-oriented behaviour are desirable (Suddendorf & Busby, 2005).

To ensure that children are relying on episodic foresight when engaging in future-oriented behaviour, it is important that studies examine novel behaviours (Suddendorf & Corballis, 2010). When adults place wallets and keys in their pocket in the morning, they frequently do so without explicitly considering future situations in which these items will become useful. Indeed, such preparatory behaviour can become automatic with repetition. Children, too, may engage in habitual future-oriented behaviour based on previous learning or parental scaffolding. To determine that a child has used episodic foresight, tests should therefore focus on problems that children have only had controlled exposure to. Of course, there remains the difficult problem of motivation—many children may not be sufficiently engaged by a task to demonstrate their foresight competence, and so false negatives can be an issue. By using novel problems, however, studies can at least reduce the risk of false positives.
Episodic foresight can guide a host of adaptive, novel future-oriented behaviours and so can be evident in diverse contexts: for example, selecting objects for future use; delaying gratification to increase the size of a reward in the future; acting based on an anticipated desire rather than a current one; and learning a rule for future use. Only some of these contexts, however, have so far received significant attention from the developmental literature. In the following sections we review the available evidence, evaluate the methodologies and identify some potential avenues for future research. Throughout the review we relate the evidence, both positive and negative, back to the development of the proposed components of episodic foresight discussed in the previous section.

**Selecting objects to be used in a specific future episode**

Human adults characteristically carry objects such as keys, wallets and other tools that they anticipate will be needed in the future (Suddendorf, 2006). We like to be prepared. Although preschoolers initially have their lunches and jackets packed by adults, they eventually learn to choose to carry objects by themselves in anticipation for a future episode when these items will be useful. Suddendorf (1994) proposed a two-rooms experimental design to test children’s developing foresight by allowing them to select and transport an object from one room—where it is useless—to another where it is useful. Indeed, Tulving (2005) endorsed such a future-directed approach as a behavioural measure of episodic memory. In a preliminary study, children were first taken to a plain room containing only a puzzle board but no puzzle pieces, and then to a second room where, after having been distracted for five minutes, they could secure the missing puzzle pieces for a return to the first room (Suddendorf & Busby, 2005). Four- and 5-year-olds, but not 3-year-olds, were more likely to select the puzzle pieces amongst several distracters than in a control condition in which they had not been shown the empty puzzle board.

Atance and Meltzoff (2005) showed children a picture book containing several scenes (e.g., a desert) and told them to pretend they were going to visit each scene. They were then offered a list of three objects and asked which one they would need to bring with them on their visit. Although 4-year-olds typically chose the correct object when the distracter items were entirely unrelated to the scene, they remained prone to choosing distracters that were semantically related to the scene but not actually required for the future episode (e.g., the majority chose to take a fish to a dangerous stream instead of taking a band-aid). The 5-year-olds, however, scored near ceiling even when the distracters were semantically related to the scene.

In another study, Russell and colleagues (2010) let children first play a form of table football against an experimenter. They were then asked which two items (out of six) they would need to play on the other side of the table either ‘right now’ or ‘tomorrow’. Because the child was too short to reach the top of the table on the other side, the correct items were a box to stand on and a straw to blow the ball with. The results showed that 4-year-olds could pass the present task, but they could
only pass the tomorrow task if they were asked to imagine what a peer would need to play tomorrow. However, there are some methodological concerns. First of all, the problem itself was evidently very difficult for children, as only 33% of participants in the present condition could solve the problem without it having any temporal element whatsoever. In order to disentangle the basic capacity for foresight from later-developing problem-solving capacities, experiments should employ problems that can be easily solved in the present context. Secondly, in the ‘tomorrow’ condition, the children were asked to imagine a future event occurring towards an apparatus they were currently observing. Hence, although the children were linguistically invited to step out of the present context in their approach to the problem, many of them simply could have solved the task using, in the authors’ own words, “purely functional reasoning such as ‘anybody who plays on the blue side will need the box’” (p. 59).

To ascertain that a behaviour is driven by an episodic capacity, Suddendorf and Corballis (2010) advocate four criteria that rule out common alternative explanations for apparent future-directed behaviour: (i) the use of single trials, to avoid repeated exposure to the same stimulus–reward relationships and to demonstrate memory of a specific event; (ii) the use of novel problems, to avoid relevant learning histories and to demonstrate that cognitive processes drive the behaviour; (iii) the use of different temporal and spatial contexts for exposure to the problem and the crucial future-directed action, to avoid cuing and to demonstrate long-term memory; and (iv) the use of problems from different domains, to avoid specific behavioural predispositions and to demonstrate flexibility. A recent developmental study was designed with these criteria in mind (Suddendorf, et al., 2011). Children were introduced to a problem in one room (a box that needed a specially shaped key to open it, or a puppet that liked a specific food) before being taken to another room and distracted for 15 minutes. They were then told they would be returning to the first room and were allowed to take one of several objects (one of which was the solution to the future problem) with them. Four-year-olds but not 3-year-olds chose the correct item above chance. In an instant version of the task, however, children from both age groups performed near ceiling. Hence, although the problems were conceptually easy, only the 4-year-olds demonstrated a capacity use information from a specific past episode and act to prepare for a return to these problems. A control experiment confirmed that temporal rather than spatial displacement was critical to performance.

These findings demonstrate that by 48 months of age, at least, human children have a capacity for episodic foresight. They can remember a novel problem sufficiently enough to secure its future solution (for similar findings, see Scarf, et al., 2013). Of course, the future that children prepare for in this paradigm is the very next event, albeit one in another room. In a recent follow-up study, however, we found that 4-year-olds similarly performed above chance even when informed that they would not be returning to the first room until a 5-minute sand-timer had
completed its cycle (Redshaw & Suddendorf, 2013). Thus, 48-month-old children can clearly act prudently to bring about an anticipated future scenario, consistent with the developments of the episodic foresight components reviewed earlier. Further experimentation varying the time between action and implementation, the tasks, the distractors and behavioural options, may help to clarify young children’s competencies and limits.

**Choosing to delay gratification to increase the size of a reward in the future**

To take advantage of future opportunities, we must sometimes forego presently desirable activities in favour of intuitively unappealing, but in the longer term more rewarding choices. Such situations have been studied with choice-based delay of gratification tasks, in which a child must choose between a larger reward to have in the future or a smaller reward to have in the present (Mischel & Metzner, 1962). Whereas the wait-based task introduced earlier only requires the inhibition of a prepotent response, the choice-based task instead focuses on the choices that children make when given the opportunity to allocate varying rewards to their present or future self (Lemmon & Moore, 2007). Until around four, children are very much present-oriented in these choices (Lemmon & Moore, 2007; Moore, Barresi, & Thompson, 1998). Yet, even older preschoolers’ preferences are influenced by salience of the present reward (Patterson & Carter, 1979), the size of the future reward (Garon, Longard, Bryson, & Moore, 2012; Lemmon & Moore, 2007), and the length of time that they have to wait for the future reward (Garon, Johnson, & Steeves, 2011). The executive component of episodic foresight appears to play an important role in these patterns, as suggested by associations between performance on choice-based delay of gratification tasks and various inhibition tasks (Moore, et al., 1998; Moore & Macgillivray, 2004). Improvements on choice-based delay of gratification tasks are seen throughout childhood and adolescence (Green, Fry, & Myerson, 1994; Mischel & Metzner, 1962).

Metcalf and Atance (2011) examined when children can learn from their lack of inhibition preventing them from receiving a large reward. In their experimental set-up, 3- to 5-year-old children visited two rooms. In each room there was a marble run apparatus—a simple one in the first and a much more elaborate and interesting one in the second—which allowed the children to place a marble at the top and then watch as it made its way through the apparatus to a trap at the bottom. After these had been introduced, the children were given three marbles and told they would be able to use them on sequential visits to each room. After visiting the two rooms, children were provided with three more marbles and a second trial of sequential visits to the rooms ensued. The results showed that, while there was some evidence of saving the marbles for the interesting apparatus on the first trial, there was a significant increase in saving on the second trial. Hence, after experiencing a failure to deploy executive resources that would have increased the reward, preschoolers can learn to show greater inhibition when a second opportunity arises.
Acting based on an incongruent future desire

It is one thing to be able to inhibit an impulsive behaviour in order to increase the size of a future reward that is currently desired, and quite another to be able to act based on a future reward that is not currently desired. Indeed, this ability has been proposed to separate humans from other extant animals (Bischof-Köhler, 1985; Bischof, 1985; Suddendorf & Corballis, 1997). And yet, even adult humans often struggle to override their current desires when engaging in future-oriented behaviour, as exemplified by the finding that people tend to buy more groceries when shopping while hungry than when shopping while sated (Nisbett & Kanouse, 1969). One might therefore expect young children to find such behaviour particularly difficult.

The two-room paradigm discussed in the object choice section was initially proposed to test when children can prepare for a state such as thirst while they are currently quenched (Suddendorf, 1994). Such a test has proven difficult to implement, although Atance and Meltzoff (2006) have come some way. They gave half of participating preschoolers some thirst-inducing pretzels to eat. All children were then offered the choice to have pretzels or water ‘now’ or ‘tomorrow’. The children who had first eaten pretzels preferred to have water, regardless of whether they would be receiving it immediately or the next day. The baseline children who had not eaten pretzels, however, preferred to have pretzels in both temporal conditions. Three, 4- and 5-year olds did not differ in their preferences. These findings suggest that the thirsty children in the ‘tomorrow’ condition were unable to act based on their future baseline level of thirst. By age 5, children can consider minds with incongruent states to their own, so why do they struggle here? Perhaps insufficient executive control is the key. It may require a considerable amount of effort to inhibit the impulse to act on such a salient feeling as salt-induced thirst. Alternatively, perhaps thirsty 5-year-olds simply do not consider that their level of thirst will have returned to its baseline state by the next day. This failure could arise from both an immature set (as the child underestimates the amount of time that will pass between making and receiving the choice) and director (as the child fails to recognise and adjust for the initial underestimation). Only future research with children at an age where performance levels are transitional will be able to pinpoint which components are responsible.

Prospective memory

Once a future scenario can be conceived, we can not only prepare for or shape the future through current action, but also form the intention to perform an action given a particular future event or at a specific future point in time. Once such an intention is formed, a new challenge is to remember that intention and act upon it when the time comes. This memory for an intention is known as prospective memory and has been extensively studied (Ellis & Kvavilashvili, 2000; Kvavilashvili, 1992). In such studies, an experimenter typically informs participants what they will
have to do given either a certain event or time interval (Kvavilashvili, Kyle, & Messer, 2008). Klögel and Jäger (2007), for example, presented 2- to 6-year-olds with picture cards to name, and the event-based prospective memory task was to place any pictures of apples within a box. In the ‘no memory aid’ condition, the box was behind the children and out of sight; in the ‘memory aid’ condition, the box remained in front of the children and visible throughout the task. In the no memory aid condition, the 4-year-olds performed significantly better than the 3-year-olds, who performed close to floor level. However, the 3-year-olds’ performance was significantly increased in the ‘memory aid’ condition, suggesting they are sometimes able to succeed on prospective memory tasks, as long as there is an external cue to trigger their memory of the rule. Four-year-olds, on the other hand, can succeed even without such cues. Children continue to improve on more difficult versions of event-based prospective memory tasks throughout the middle and late childhood years (Kvavilashvili, et al., 2008), potentially due to quantitative improvements in working memory and complex forms of executive function (Guajardo & Best, 2000).

Time-based prospective memory research has typically focused on school-aged children (Ceci & Bronfenbrenner, 1985; Kerns, 2000; Mackinlay, Klögel, & Mäntylä, 2009), requiring them to carry out an action when a clock shows a specific time or when an alternative timing device has completed a cycle. The youngest reported success on a time-based task is by 5-year-olds, who performed adequately when they were required to turn a sand-timer over whenever it had completed a cycle—while also playing an unrelated game (Kliegel, Brandenberger, & Aberle, 2010). Still, one may question whether these tasks really measure time-based prospective memory in isolation. One can solve the tasks through a time-dependent yet still event-based rule such as: do X when all the sand has dropped, or when the clock shows this or that pattern. Therefore, we are not convinced that any current research documents the development of truly time-based prospective memory, and recommend such work be conducted.

More importantly, we know next to nothing about how children develop the capacity to generate their own intentions based on their own episodic foresight. In prospective memory research the experimenter does this important work for the children and instructs them what to do and when. It is possible that children are scaffolded through the instructions adults give them. Future research should therefore examine when children have the cognitive resources to instruct themselves about what they intend to do in the future. Such research might wish to measure, for example, children’s ability to spontaneously set an alarm that will remind themselves to perform a novel future task.

**Future Directions**

In addition to the specific avenues for future research alluded to in the previous sections, there are some more general developmental questions ripe for investigation. Deliberate practice, for
instance, is a fundamentally important behavioural corollary of episodic foresight that has so far been neglected by developmental psychology. We can choose to practice a skill or rehearse information in light of what we foresee to be their future utility. Much of human diversity in expertise is a function of the fact that children selectively devote distinct efforts towards learning certain knowledge and practicing particular skills. Children begin to play (Cohen, 2006; Fein & Apfel, 1979) and ask questions (Gopnik & Meltzoff, 1997) from a very young age, incidentally learning actions and information that will come in handy throughout their lives. Surprisingly little, however, is known about when children begin to deliberately practice skills or obtain knowledge to solve particular future problems.

The factors that facilitate or hinder the development of effective episodic foresight also deserve more research attention. We have seen that parents who produce more elaborate past and future narratives have children who produce more detailed linguistic descriptions of the past (Fivush, 2011) and the future (Hudson, 2006). However, whether this effect extends to the actual capacity, rather than merely its expression, remains to be seen. There are programs and activities that improve children’s executive functions (Diamond, 2012), and this, or similar training, may potentially also enhance children’s episodic foresight. The role that deficits in episodic foresight may play in the development of various conditions and psychopathologies also deserves further scrutiny. Children with autism, for example, who struggle to represent the perspectives of other people (Baron-Cohen, Leslie, & Frith, 1985), may have similar troubles representing their own future perspectives (Lind & Bowler, 2010; Suddendorf & Corballis, 1997).

Critically, more research is required on the relationship between brain maturation and the development of episodic foresight and its purported components. The brain regions implicated in mental time travel closely map to the ‘default network’ (Spreng & Grady, 2010; Spreng, et al., 2009), which is highly active during wakeful rest (Buckner, Andrews-Hanna, & Schacter, 2008; Mason et al., 2007) and may be more generally implicated in the construction and maintenance of coherent scenes (Hassabis & Maguire, 2009). By age 2 the default network becomes similar to that of adults (Gao et al., 2009). However, even in 7- to 9-year-old children the nodes are still only loosely connected, and only by early adulthood does activity become tightly interlinked and temporally correlated (Fair et al., 2008). Default network activity shifts from the orbital prefrontal cortex at age two (Gao, et al., 2009), to more ventral/dorsal prefrontal regions—which have been implicated in self-reflective processing (Amodio & Frith, 2006)—from age five onwards (de Bie et al., 2011; Gao, et al., 2009). Between ages 3 and 5 the cortex is expending more energy per unit volume than at any other time (Chugani, Phelps, & Mazziotta, 1987), correlating with the emergence of many of the episodic foresight components and future-oriented behaviours reviewed herein. As yet, however, there is no published research on the development of the default network.
during this period. Interestingly, an infant-like pattern of orbital prefrontal activity is also seen in the default network of our closest living animal relative, the chimpanzee (Rilling et al., 2007). Future research could examine whether the differences between chimpanzee and adult human default networks mirror the developmental refining of the human default network, and so potentially link research on the development of episodic foresight with research on the capacities and limits of chimpanzees (Mulcahy & Call, 2006; Osvath & Osvath, 2008; Suddendorf & Corballis, 2007, 2010; Suddendorf, Corballis, & Collier-Baker, 2009).

Neural correlates of the purported components of mental scenario building deserve more research attention in their own rights, as well as in the context of enabling foresight. We saw that many relevant components keep developing long after age five, and foresight capacities keep improving into young adulthood. Neural changes, too, continue well beyond early childhood, and such changes may correspond to later cognitive developments. From ages eight to fourteen, for instance, the absolute and relative volume of the prefrontal cortex almost doubles (Kanemura, Aihara, Aoki, Araki, & Nakazawa, 2003), perhaps increasing the role of this region in the default network. Throughout adolescence cortical grey matter becomes thinner and white matter increases—synapses are pruned and axons become increasingly myelinated (Huttenlocher, 1990; Paus et al., 1999). Adolescents gradually improve in their capacity to prudently control behaviour, becoming increasingly capable of self-discipline and resistance to temptation. Indeed, even on relatively simple tasks such as “when a light appears on the left of the screen look to the right; when it appears on the right look left”, inhibition errors only gradually decrease across adolescence (Luna, Garver, Urban, Lazar, & Sweeney, 2004; Luna et al., 2001). Recent work suggests that white matter connectivity continues to mature even later (Asato, Terwilliger, Woo, & Luna, 2010), with the uncinate fasciculus, a white matter tract associated with emotional processing linking orbitofrontal cortex, amygdala and temporal regions, peaking only in the mid-thirties (Lebel et al., 2012). The causal relations between our developing brain and the emergence of our increasingly prudent prospective minds remain to be uncovered.

**Conclusion**

Episodic foresight is arguably a quintessential human faculty that is employed in many domains. There may be some degree of freedom in its development in different individuals, depending on the cultures, teachers, models and individual idiosyncrasies. Little as yet is known about such differences and what may foster or inhibit the development of episodic foresight. The basic capacity is a human universal, however, and so the fundamental steps in its development may emerge in a predicable fashion. Our review indicates that children between age 3 and 4 acquire many milestones in the components proposed to be involved in episodic foresight. The pattern of development differs between components, suggesting that different aspects of foresight may
develop at different times. More direct measures of future-directed capacities also highlight the importance of the preschool years as children demonstrate foresight when asked directly or examined with future-directed problems. So this period appears to represent a watershed, even though evidently there are important developments before and after.

Only one published study so far has tested associations between multiple future-oriented tasks (Atance & Jackson, 2009). The seven tasks in this study were: a question about what the child was going to do ‘tomorrow’, a picture book that required children to select objects to be taken to specific future scenes, a wait-based delay of gratification task, two prospective memory tasks, and two tasks measuring other aspects of planning (a modified version of the Tower of Hanoi and a route-planning task). After controlling for age and vocabulary, the only two positive correlations were between the tomorrow task and the picture book task, and the tomorrow task and one of the prospective memory tasks. If one conceives of episodic foresight as a single encapsulated cognitive module, as a unitary ability that children either do or do not have, then a lack of many significant correlations would be concerning. However, the view that episodic foresight depends on the maturation and interaction of a range of sophisticated components predicts a far more complicated developmental pattern. Children may begin to solve one kind of task and yet be incapable of another, depending on the demands on components involved.

Our own foresight indicates that much more research will be conducted to disentangle what exactly is involved in each task, and new measures will be developed to isolate specific competencies. We have only very recently begun to investigate the nature and development of this important human faculty.
References


Hudson, J. A. (2002). "Do you know what we're going to do this summer?": Mothers' talk to preschool children about future events. *Journal of Cognition and Development, 3*(1), 49-71.


A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 115-140). New York: Lawrence Erlbaum.


Chapter 3

Foresight Beyond the Very Next Event: Four-year-olds can Link Past and Deferred Future Episodes
Preface

Chapter 2’s review revealed that crucial developments in episodic foresight are achieved throughout childhood and beyond. It also revealed, however, that many future-oriented behaviours remain entirely unexamined in children. I now move onto the empirical section of my thesis, in which I examine the development of several novel future-oriented behaviours. This section mainly focuses on children aged between three and five years because, as the review has shown, this period appears to be particularly critical in the development of the identified episodic foresight components and often marks the first appearance of various future-oriented behaviours. If my research can establish the typical age of initial evidence for novel future-oriented behaviours, then it will enable future studies to identify the particular cognitive maturations that may be driving change at the behavioural level.

To begin with, the following chapter assesses 4-year-old children’s capacity to recall a problem from the past and act in the present to solve that problem for a deferred future episode. This study uses an adaptation of the two-room paradigm first introduced by Suddendorf and Busby (2005), and later refined by Suddendorf, Nielsen, and von Gehlen (2011).

The published version of this chapter was mentioned in Chapter 2, and this chapter likewise references the published version of Chapter 2. The reason for this cross-referencing is that both chapters were published at roughly the same time, in mid-2013. Because this chapter is an adapted version of a published article, many of the concepts and findings mentioned in the previous two chapters are briefly reiterated.

Abstract

Previous experiments have demonstrated that by four years of age children can use information from a past episode to solve a problem for the very next future episode. However, it remained unclear whether four-year-olds can similarly use such information to solve a problem for a more removed future episode that is not of immediate concern. In the current study, we introduced four-year-olds to problems in one room before taking them to another room and distracting them for 15 minutes. The children were then offered a choice of items to place into a bucket that was to be taken back to the first room when a five-minute sand-timer had completed a cycle. Across two conceptually distinct domains, the children placed the item that could solve the deferred future problem above chance level. This result demonstrates that by 48 months many children can recall a problem from the past and act in the present to solve that problem for a deferred future episode. We discuss implications for theories about the nature of episodic foresight.
Much of human cognition involves mental time travel to past and future episodes (Buckner & Carroll, 2007; Smallwood et al., 2011), a capacity that allows effective preparation for and active shaping of future events (Suddendorf & Corballis, 1997). At their core, both episodic memory and episodic foresight require self-projection into a non-current perspective (e.g., Buckner & Carroll, 2007; Suddendorf & Corballis, 2007), and one might therefore expect these abilities to draw on similar neurocognitive resources and develop at a similar age. Supporting the case of neurological similarity, both abilities engage similar brain networks (Addis, Wong, & Schacter, 2007; Okuda et al., 2003; Spreng & Grady, 2010; Spreng, Mar, & Kim, 2009); both show similar declines in old age (Addis, Wong, & Schacter, 2008); and both are selectively impaired in hippocampus-lesioned amnesiacs (Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002; Rosenbaum, Gilboa, Levine, Winocur, & Moscovitch, 2009; Tulving, 1985). And indeed, children who can accurately report events from yesterday are more likely to accurately report events that will happen tomorrow (Busby & Suddendorf, 2005; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011; Suddendorf, 2010). These commonalities support the view of episodic memory as a crucial design feature of the episodic foresight system (Suddendorf & Busby, 2005). Episodic memories provide a rich database of information that can be mentally recombined into similar and even entirely novel future episodes to guide prudent behaviour (Schacter & Addis, 2007; Suddendorf & Corballis, 2007). Only recently, however, have studies begun to examine when and how this capacity to link past, present and future develops in children.

The ability to use information from a past episode to prepare in the present for a future episode is a useful test of mental time travel in both non-verbal animals and children whose verbal responses may belie their true cognitive abilities (Hampton & Schwartz, 2004; Scarf, Gross, Colombo, & Hayne, 2013; Suddendorf & Busby, 2005; Suddendorf & Corballis, 2008; Tulving, 2005). Suddendorf and Corballis (2010) distil four criteria that studies of this capacity must meet in order to rule out alternative explanations: (i) use of single trials, to avoid conditioning and demonstrate memory for a specific event; (ii) use of novel problems, to engage cognitive processes and eliminate learning history explanations; (iii) use of separate spatial/temporal contexts for the crucial future-directed action and the future problem, to avoid cuing to the answer and demonstrate long-term memory; and (iv) use of multiple problems from distinct domains, to demonstrate the domain-general nature of the capacity. Compelling positive evidence meeting these criteria has not yet been obtained for animals (Suddendorf & Corballis, 2010), and some studies of children also fail to meet them. In a recent study by Russell and colleagues (2010), for example, the future problem was visible to the children during the future-directed action (violating criterion iii), such that the successful children did not necessarily have to base their solution on a spatially and temporally removed mental construction.
Suddendorf and colleagues (2011) designed a series of experiments that did meet the four criteria outlined above. In one of these, 3- and 4-year-olds were introduced to one of two conceptually distinct problems in an initial testing room. The ‘box task’ involved a box with a triangle-shaped keyhole and the ‘food task’ involved a puppet that wanted to eat a banana. In the instant condition, the child was led to the other side of the room immediately after being presented with the problem, and was allowed to choose a solution from a selection of three items without being allowed to look back at the problem. In the delay condition, the child was taken to a second room and distracted for 15 minutes. They were then offered the same choice of items for an immediate return to the first room. Importantly, the experimenter did not refer to the problem in either condition, only its location. In the instant condition, both 3- and 4-year-olds selected the item that could solve the problem at levels close to ceiling. In the delay condition, however, only the 4-year-olds selected the item that secured the future solution significantly above chance level.

These results clearly demonstrate the effect of a delay between the relevant past event and the future-oriented action on children’s ability to link past and future episodes. Only 4-year-olds demonstrated a capacity to import a past event from long-term memory into working memory and act for the future. Still, the very next event following item selection was a return to the problem, and so, while the future problem had to be imagined, in some sense it may have been part of the child’s psychological present. Even 2-year-old children (Bauer, Schwade, Wewerka, & Delaney, 1999) and non-human great apes (Döhl, 1968; Koehler, 1927) show some ability to mentally simulate and act for the ‘future’, when that future is part of a single ongoing event and long-term memory is not required. This ability likely relies on working memory in much the same way as the ability to recall and manipulate information that has been encountered in the very recent past. As adults, however, we frequently prepare for more remote future events, and we rely on our long-term memory for what was required in similar past episodes to guide our future-oriented actions. It is possible that imagining and acting for a deferred future episode requires more executive resources than for a future episode that has become of immediate concern, such as the episode in Suddendorf and colleagues’ (2011) task. Would 4-year-olds be capable of solving this task if a series of irrelevant events was inserted between the future-directed action and the return to the original problem? Can they link past and future episodes that are both temporally removed from the immediate?

Attempts to test for episodic foresight beyond the very next event must overcome the difficult problem of how to inform a child participant just when in the future their present behaviour will have an effect (Suddendorf, et al., 2011). Young children, especially those aged four and under, have considerable trouble understanding and correctly using specific future-oriented terms (Busby Grant & Suddendorf, 2010, 2011; Harner, 1975, 1980). Therefore, informing them that
their choice of an item will have an effect when they go to another room in ‘five minutes’ or play a game ‘tomorrow’ (e.g., Russell, et al., 2010) would be futile for a large proportion of young children. However, as children generally understand concrete instantiations of concepts earlier than they understand symbolic representations (Uttal, Scudder, & DeLoache, 1997), it may be more effective to convey the delay with a sand-timer. A previous study revealed that most 4-year-olds understand that a half empty sand-timer will complete its cycle before a full one (Bischof-Köhler, 2000), suggesting they correctly recognise something about how the amount of sand in the compartments changes over time.

The current experiment built on Suddendorf and colleagues’ (2011) methodology to test whether 4-year-olds could remember a problematic past episode from 15 minutes ago and prepare for a deferred future episode marked by the completion of a sand-timer’s cycle. Rather than choosing an item to immediately take into the problem room, the children instead had to place the item into a bucket, which they were previously told would be taken to the problem room only when the timer had completed its cycle. The inclusion of the bucket crucially required the children to physically separate themselves from their chosen item, thus reinforcing the idea that the item was to be ‘saved’ for a deferred future episode rather than used in the immediate future. An instant condition with no delay in either temporal direction was included to confirm that the problems themselves were conceptually easy.

Method

Participants

Twenty-four 4-year-olds ($M = 48$ months 17 days, $SD = 14$ days) were included in the study. This group consisted of 10 boys and 14 girls, who each participated individually with a parent or caregiver present. Each child completed both the box task and the food task, one in the instant condition and one in the delayed condition. The orders of the tasks and conditions were counterbalanced.

Materials

The experimental materials for the box task and the food task were identical to those used in experiment two of Suddendorf and colleagues’ (2011) study, with the exception that more distracting objects were included to lower the level of chance performance and thus increase experimental power.

Box task. Two wooden boxes (14 x 21 x 21 cm) were used in this task, each featuring a large keyhole (either square- or triangle-shaped) on the front panel. Sliding an appropriately-shaped key into these keyholes activated a mechanism that revealed a previously hidden platform within the box, allowing objects to be retrieved from the platform. Seven different keys were used in the
task, each consisting of a wooden shape connected to a 19 cm rod. The seven shapes were: square, triangle, circle, star, heart, teardrop, and an irregular zigzag shape.

**Food task.** Two commercially available hand puppets (a tiger and an elephant) were used, along with seven plastic foods: strawberry, banana, apple, pear, orange, grapes, and carrot. 

**Sand-timer and bucket.** One commercially available cylindrical sand-timer (height 16 cm, diameter 8 cm) with blue sand grains was used to communicate the delay to the child. The time of a complete cycle was approximately five minutes. A black bucket was also used, in which the child was to place their selected item in the delayed condition.

**Procedure**

Prior to the main sequence of the experiment, the child was taken to a warm-up room where they were introduced to the time-keeping nature of the sand-timer. The sand-timer was turned over and the child was asked to examine the sand falling from the top to the bottom compartment. The child was informed that they would receive a sticker once all of the sand had reached the bottom.

After this introduction, the child was taken to Room A, referred to as “Charlie the chicken’s room” owing to a large poster of a chicken on the wall. In this room they were presented with the box task and the food task while seated at a child-friendly table.

**Box task.** The experimenter introduced the child to the box with the square-shaped hole, and demonstrated how to use the square-shaped key to activate the mechanism and reveal a hidden toy. The child was allowed to perform this action themselves, before the demonstration was repeated and the child was allowed to have a second attempt. This box was then removed and the box with the triangle-shaped hole was introduced. The experimenter demonstrated to the child that the square-shaped key did not work on this box, and the child was allowed to confirm this for themselves.

In the instant condition, the child was then led to the other side of the room, where the triangle-shaped key and five distracter keys were located. Without being able to look back at the test table, the child was asked to pick one of these items to take back.

In the delayed condition, the child was told that they would go to another room (Room B) to play some games, and the box with triangle-shaped keyhole was left on the table. After 15 minutes of unrelated activity in Room B, the child was reintroduced to the sand-timer and shown the bucket. They were informed that (i) they would be going back to Charlie the chicken’s room after the sand-timer had completed a cycle, and (ii) they would be taking the bucket with them when they went. The child was asked to independently generate these facts consecutively to ensure that they understood exactly what would be happening and when. Finally, the experimenter revealed a previously hidden tray containing the triangle-shaped key and the five distracter keys, and invited the child to place one of these items only into the bucket. After they had made their choice, the
child was asked to explain the reason for their selection. Upon completion of the sand-timer’s cycle, the child was invited to bring the bucket with them to Room A where they could solve the problem (the experimenter brought the correct item if the child had not selected it).

**Food task.** The experimenter introduced the child to the tiger puppet. The child was told that ‘Terry the tiger’ liked to eat strawberries and the child was allowed to ‘feed’ the puppet using the visible plastic strawberry on the table. This procedure was repeated, before the child was introduced to the elephant puppet and told that ‘Ellie the elephant’ liked to eat bananas. The experimenter then pointed out that there were no bananas to feed Ellie.

The instant and delayed conditions mirrored those of the box task, except that the items available to choose were the plastic banana and the five plastic food distracters.

**Results**

A 2 x 2 ANOVA (Task x Condition) revealed a main effect of Condition, with the children selecting the correct item significantly more often in the instant condition than the delayed condition, \( F(1, 22) = 12.79, p = .002 \). There were no significant effects involving Task, suggesting that the box and food tasks did not vary in difficulty in either condition. There were also no significant condition order effects, suggesting that the presentation order of the instant and delayed conditions did not affect the children’s performance. We have therefore collapsed across these variables in the subsequent analyses.

As seen in Figure 1, the large majority of children selected the appropriate item (91.7%) in the instant condition, a performance that was well above chance level (16.7%), \( \chi^2(1) = 97.20, p < .001 \). This finding confirmed that the problems themselves were conceptually easy when the temporal element was absent. Although performance was decreased in the delayed condition, the children still selected the appropriate item (50%) well above chance level, \( \chi^2(1) = 19.20, p < .001 \).
The conclusion that the children displayed some foresight when selecting the item in the delayed condition is supported by their verbal responses. Across tasks, 25% of children made reference to the future utility of the item when explaining their choice. All of these children had selected the correct item, a performance that was well above chance level, $\chi^2 (1) = 30.00, p < .001$. Of the 75% of children that did not make future reference when explaining their choice, one third of them had still selected the correct item. Nevertheless, the rate of correct item selection among this sub-sample was not significantly above chance level, $\chi^2 (1) = 3.60, p = .058$.

**Discussion**

The current study examined whether 4-year-olds could remember a problem from a specific past episode and act in the present to obtain a novel solution for a return to the problem in a deferred future episode. In the delayed condition, the children had to independently confirm their understanding that they would be returning to Room A with the bucket after the familiar sand-timer had completed its cycle. This process ensured that the children understood the item they subsequently placed into the bucket was not to be used in the immediate future, but rather saved for the deferred future episode in Room A. And, although they did not perform at the same level as in the instant condition, they still selected the correct item well above chance level. The current study therefore demonstrates, for the first time, that many 4-year-olds can use information from past episodes to prepare for deferred future episodes, just as they can for otherwise identical future episodes of immediate concern (Suddendorf, et al., 2011).
The findings of the current study add to the growing developmental literature that has emerged following recent widespread recognition of the importance of human episodic foresight and its links to episodic memory (Science, 2007). Developmental milestones appear to be achieved over the preschool years (Suddendorf & Moore, 2011; Suddendorf & Redshaw, 2013). During this period, children begin to show competence on tasks requiring them to delay gratification for the future (Garon, Longard, Bryson, & Moore, 2012; Mischel, Shoda, & Rodriguez, 1989; Moore, Barresi, & Thompson, 1998), save resources for the future (Atance & Meltzoff, 2005; Metcalf & Atance, 2011), place multiple future episodes in time relative to each other (Busby Grant & Suddendorf, 2009; Friedman, 2000; Hayne, et al., 2011; Hudson & Mayhew, 2011), learn a rule to be applied in the future (Kliegel & Jäger, 2007), plan an intervention that will help a character in the future (McColgan & McCormack, 2008; McCormack & Hanley, 2011), and evaluate the likelihood of future events (Lagattuta & Sayfan, 2011). The current study documents the development of another key future-oriented capacity: adaptively linking past and deferred future episodes.

**Potential implications for the nature of episodic foresight**

The performance of the 4-year-olds in the delayed condition (50% success, with a chance level of 16.7%) closely matches that of the 4-year-olds in Suddendorf and colleagues’ (2011) second experiment, in which the future episode immediately followed the crucial future-oriented action (58.3% success, with a chance level of 33.3%). Perhaps then, as long as the relevant past episode can be imported into working memory, we can use the same cognitive mechanism to prepare for a similar future episode whether that future episode is the very next event or several minutes removed. So, as long as we can remember the shampoo bottle running out last night, we can use the same mechanism to replace it with a full one whether we are going to shower immediately or in preparation for a shower in five minutes time. This observation raises the possibility that the same mechanism can even be used to prepare for more distant future episodes, such as next summer’s holiday, again as long as the relevant past episode is recalled. Such an interpretation is consistent with the strong neurological links between episodic memory and episodic foresight described in the introduction, and with the idea that episodic memory may have evolved as a crucial design feature of the episodic foresight system.

If imagining immediate and deferred future episodes can be achieved with the same basic mechanism, then it may follow that children (and adults) will tend to use this mechanism as a heuristic when preparing for any deferred future episode—even when additional mechanisms are required. Consistent with Read and Loewenstein’s (1995) time contraction hypothesis, we may not be equally motivated to prepare for immediate and distant future events, as a large body of temporal discounting literature disproves (e.g., Green, Fry, & Myerson, 1994; Green & Myerson, 2004). Future events are increasingly uncertain as they move further away, and so our lack of enthusiasm for preparing for distant episodes is sometimes justified. Still, the current study may indeed suggest that linking past events with deferred future events is not more cognitively demanding in principle than for immediate future events.

---

1 This is not to say we are equally motivated to prepare for immediate and distant future events, as a large body of temporal discounting literature disproves (e.g., Green, Fry, & Myerson, 1994; Green & Myerson, 2004). Future events are increasingly uncertain as they move further away, and so our lack of enthusiasm for preparing for distant episodes is sometimes justified. Still, the current study may indeed suggest that linking past events with deferred future events is not more cognitively demanding in principle than for immediate future events.
typically imagine and prepare for any future episode as if it were occurring in the immediate future; as if the current self were placed into that episode with a time machine. Nevertheless, our current motivation, emotion, and knowledge states are not always the same as our future states, and so we must sometimes prepare for a deferred future episode containing a self that differs from the current self on some important dimension (Suddendorf & Corballis, 1997). Both children (Atance & Meltzoff, 2006) and adults (Nisbett & Kanouse, 1969) often fail to take this difference into account when required, despite the fact children begin to demonstrate a capacity to imagine minds with distinct states to their own around age four (Wellman, Cross, & Watson, 2001). These specific theory-of-future-mind failings may be explained by the routine use of a generally successful heuristic that places the current self into the future episode.

**Future directions and conclusions**

The current study was designed only to answer the specific question of whether 4-year-olds could prepare for a deferred future event just as they can for the very next future event, and we found that indeed they could. Future studies may want to vary the temporal delay between the item selection and the future event. It is possible that the same basic mechanism can be used to prepare for an immediate future event and one that is happening in five minutes, but additional mechanisms are required to prepare for an event happening next year. Such a finding would provide evidence against the heuristic view we have presented above, which theoretically should apply to any non-immediate future event. Other studies may want to vary the temporal period in which an item becomes useful, such that the item that is useful immediately is not the same one that is useful in five minutes or in ten minutes. Selecting only the time-appropriate item may require complex inhibition skills, which 4-year-olds are still in the process of learning (Diamond & Taylor, 1998; Gerstadt, Hong, & Diamond, 1994).

In conclusion, the current study has demonstrated, for the first time, that 4-year-olds can remember a problem from a specific past episode and act to solve that problem for a deferred future episode, just as they can for the very next future episode. Future-oriented action may be achievable with the same episodic foresight mechanism whether or not intermediate events are located between that action and the relevant future episode.
References


Metcalf, J. L., & Atance, C. M. (2011). Do preschoolers save to benefit their future selves? 


Chapter 4

The Development of Future-oriented Information Seeking and Encoding
Preface

Chapter 3’s study used the two-room paradigm (Suddendorf & Busby, 2005; Suddendorf, Nielsen & von Gehlen, 2011) to show that many 4-year-olds could recall a problem from the past and act to solve that problem for a deferred future episode, which was marked by a 5-minute sand-timer. The usefulness of the two-room paradigm, however, is not limited to studies of children’s future-oriented object selection. Rather, it can also be used to assess the development of other future-oriented behaviours where control over contextual cuing is desired.

The following chapter uses the two-room paradigm (in Study 1) to assess 4- and 5-year-old children’s capacity to seek information that will only be useful in a specific future episode, which is a crucial aspect of human learning. I do not, however, include a five minute delay between the future-oriented action and the return to the problem, because (i) Chapter 3’s results suggest that this manipulation has no effect on children’s ability to act for the future, and (ii) sand-timers were used for other purposes with the same participants (e.g., in Study 2).

This chapter has been submitted for publication¹ and at the time of writing it is under peer review. Therefore, many of the concepts and findings mentioned in the general introduction (Chapter 1) and review (Chapter 2) are briefly reiterated.

Abstract

Despite a wealth of recent research examining children’s future-oriented cognition, there remains little known about the development of information seeking behaviour aimed at achieving specific future goals. Here we present the first experiments directly tracking the emergence of this behaviour in older preschool children. Study 1 consisted of two experiments requiring children to recall a problem from the past and seek information relevant to solving that problem in the future. Across both experiments, we found that 5-year-olds selectively sought the information that would help them solve the future problem. Four-year-olds did not perform above chance level when low-level associative explanations were controlled for, though it remained unclear what caused their poor performance. In Study 2, we reduced demands on memory as children were given an opportunity to study information for a future test. Again, we found that 5-year-olds, but not 4-year-olds, were more likely than chance to use future-directed information seeking strategies, with the use of such strategies predicting superior performance on the test questions. We conclude that many children can selectively seek information for specific future episodes by at least the fifth year of life, and discuss why this skill may emerge relatively late in development.
Humans are prolific information seekers (Biederman & Vessel, 2006; Wilson, 2000). We ask questions of each other, we exchange news and gossip, and we learn facts and theories, providing us with the knowledge to help navigate the physical and social world (Suddendorf, 2013; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Often, we seek information without any specific purpose in mind. Consider, for example, the tendency of humans and other animals to automatically orient towards changes in the environment (Sechenov, 1863/1965). Information gained in such fashion frequently proves useful, for example by allowing rapid detection of potential prey or predators, thus conferring an adaptive benefit to the behaviour. Still, in humans at least, an additional feature of information search is the ability to preference information for a particular purpose. If you wish to make dinner, for instance, you may check the contents of your fridge and pantry while deciding what to cook. Importantly, however, the goal of purposeful information search does not necessarily have to exist in the here-and-now—we can also selectively search for information that will only be useful in an anticipated future scenario (Bruce, 2005).

Many of us study in school, for example, not because of any inherent preference for the specific facts learned, nor to achieve any immediate goal, but rather because these facts are likely to become valuable during a particular future test or during other future episodes in the wider world. Yet, despite broad implications for schooling and other applied domains, to our knowledge no study has directly examined the emergence of children’s ability to selectively seek and encode information that will be useful in the future.

Young children, like adults, regularly seek unknown information. Even newborn infants look longer at novel visual displays than familiar displays (Friedman, 1972; Slater, Morison, & Rose, 1984), suggesting they possess an innate preference for new sensory material. Not long after they start speaking, children begin to habitually question others about the world using signature phrases such as “what’s that?” (Gopnik & Meltzoff, 1997). This questioning allows them to acquire information that will assist them, at times, for the rest of their lives, even if they did not seek it with any awareness of such long-term functions. And by the time they are 30 months old, many children will selectively seek out critical information with a purpose in mind, for instance when they are uncertain about the location of a reward (Call & Carpenter, 2001). It appears then, that even in the earliest years of life children possess a natural curiosity that leads to adaptive information seeking, and at least by their third year they can seek out information to help achieve a current goal. In order to harness this ability to achieve more distant goals, however, children must first be able to imagine future episodes to assess what information will likely be useful.

Envisioning specific future events, or “episodic foresight”, is the future-directed counterpart of episodic memory (Suddendorf & Moore, 2011) and is potentially unique to humans (Suddendorf & Corballis, 1997; Tulving, 2005). It should not be thought of as a single encapsulated cognitive
module, but rather as a multifaceted process involving the engagement of several distinct but interconnected components (Suddendorf & Corballis, 2007). Such components may include: the working memory capacity to construct a mental scenario removed from the here-and-now, populating that scenario with objects and mentally-endowed actors, placing the scenario in time relative to current reality, judging the scenario on dimensions such as likelihood and desirability and altering it accordingly, and inhibiting immediate impulses so that the anticipated scenario can be envisioned and actualised. Together, these components allow us to imagine virtually any future scenario and to act with specific future episodes in mind (Suddendorf & Corballis, 2007). The components of episodic foresight emerge along varying trajectories, but developments in all of them are seen between ages three and five (Suddendorf & Redshaw, 2013). And indeed, during this period children also begin to show evidence of flexible future-directed behaviour. Several recent studies have demonstrated that preschoolers can pass many tasks requiring them to act with the future in mind (for reviews, see Hudson, Mayhew, & Prabhakar, 2010; McCormack & Atance, 2011; Suddendorf & Redshaw, 2013).

Despite the consistent pattern of development during the preschool years, however, there is inconsistency regarding the more specific ages that various future-oriented capacities develop. For example, some future-oriented object selection tasks appear to be within the capacity of 3-year-olds (Scarf, Gross, Colombo, & Hayne, 2013), whereas others appear to remain out of reach until four (Russell, Alexis, & Clayton, 2010; Suddendorf, Nielsen, & Von Gehlen, 2011) or five (Atance & Meltzoff, 2005) years of age. Some temporal reasoning tasks can be passed by 3- and 4-year-olds, whereas others are passed only by five (Busby Grant & Suddendorf, 2009; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011; McColgan & McCormack, 2008; McCormack & Hanley, 2011). And some tasks requiring the inhibition of current desires in favour of future desires can be passed by 3- or 4-year-olds (Imuta, Hayne, & Scarf, 2013; Metcalf & Atance, 2011; Moore, Barresi, & Thompson, 1998; Thompson, Barresi, & Moore, 1997), whereas others cannot even be passed by 5- or 7-year-olds (Atance & Meltzoff, 2006; Mahy, Grass, Wagner, & Kliegel, 2014). Moreover, preschoolers’ performances across multiple future-oriented tasks are only weakly correlated when age is controlled for (Atance & Jackson, 2009). Such patterns make sense when episodic foresight is considered as a multidimensional capacity dependent on specific task demands (Suddendorf & Redshaw, 2013), but they also make it difficult to predict the age of competence on novel future-oriented tasks. Considering that future-oriented information seeking is particularly important during the formal schooling years, however, it would be interesting to examine whether children who are about to begin school can solve problems requiring this capacity.

An essential purpose of schooling is for children to obtain the information that will allow them to eventually become productive members of society. Yet, this need not entail that first-
Graders themselves envision the critical long-term future significance of basic arithmetic knowledge or of learning the letters of the alphabet. Instead, much of children’s early learning is imposed and scaffolded by parents and teachers. Nonetheless, children who do understand the relationship between information seeking and improved future outcomes may be more likely to seek appropriate information independently and encode it more efficiently. Initially, at least, this may be primarily driven by understanding the relatively short-term future relevance of information seeking, which in turn will have additional (and perhaps unintentional) long-term future benefits. For instance, if children understand that studying two-times tables on Thursday will help them achieve greater performance on Friday’s test, then they may be more motivated to study this information than children who do not understand the contingency.

In the current studies, 4- and 5-year-old preschoolers were given tasks requiring them to selectively seek out certain information that would benefit them in a short-term future situation, in preference to structurally similar but non-useful information. The first set of experiments required them to recall problems encountered 15 minutes earlier in a separate room and preferentially seek out information that would allow the problems to be solved in the future. The second study relaxed the memory requirement and instead gave children the opportunity to preferentially study information that would appear on a future test. Children’s performance levels on all tasks were compared between age groups and also to the levels expected by chance. These exploratory studies provide the first attempt to chart the development of an aspect of future-oriented behaviour that is fundamentally important to human learning. Indeed, our own information search here is driven by the anticipation that a clearer understanding of this development will eventually lead to opportunities to inform the design of novel interventions and enhance early schooling performance.

**Study 1**

Several authors have identified criteria that studies of episodic foresight should ideally meet in order to rule out simpler alternative explanations for results (e.g., Hampton & Schwartz, 2004; Suddendorf & Busby, 2003, 2005; Tulving, 2005). Suddendorf and Corballis (2010) propose four such criteria: (i) the use of single trials, to avoid multiple exposures to the same stimulus-response relationships and demonstrate the representation of a specific future event; (ii) the use of novel problems, to engage cognitive processes and rule out learning history explanations; (iii) the use of separate temporal and spatial contexts for the future-oriented action and the problem that it solves, to avoid contextual cuing and engage long-term memory; and (iv) the use of problems from different domains, to avoid specific behavioural predispositions and demonstrate flexibility in applying the capacity.

With these criteria in mind, Suddendorf and colleagues (2011) developed a paradigm to assess episodic foresight in preschoolers. In the critical condition of their second experiment,
children were exposed to a novel problem in one room before being taken to a second room and
distracted for 15 minutes. They were then offered a choice out of three items (one of which could
solve the problem) to take back to the first room. Four-year-olds were able to choose the correct
item above chance level. In our first study we report on two experiments, inspired by this two-room
paradigm, intended to answer the question of when children begin to seek out information with a
specific future episode in mind. Experiment 1A involves a task in which children are given the
opportunity to preferentially seek out relevant novel information (about a specific familiar puppet)
instead of irrelevant novel information (about other familiar puppets) to solve a future problem in
another room. Experiment 1B varies the context of the future problem to address some alternative
explanations for the results of the first experiment. In both experiments, we compare the capacities
of 4- and 5-year-olds to examine early competence in future-oriented information seeking.

Experiment 1A

Method

Participants. Twenty 4-year-olds (M age = 48 months 12 days, SD = 20 days) and twenty 5-year-
olds (M age = 59 months 21 days, SD = 26 days) comprised the sample of the first experiment. Ten
of the 4-year-olds and seven of the 5-year-olds were boys. Each child participated individually with
a parent or caregiver present.

Materials. Four commercially available puppets (giraffe, elephant, tiger, snail) were used as the
protagonists of the task. The other critical item was a specially constructed, landscape-oriented A4
booklet. A practice page showed three animal characters – a cat, a dog, and a rabbit. These
characters appeared on flaps that could be lifted up to reveal pictures of their favourite shapes. The
next three test pages all featured three photographs of the same three animal puppets – the elephant,
the tiger and the snail. On each page the characters appeared on flaps that could be lifted up to
reveal pictures of their favourite foods (test page 1), favourite colours (test page 2), or favourite toys
(test page 3). See Figure 1 for a representation of test page 1.
**Figure 1.** Representation of test page 1 in the booklet used in Experiments 1A and 1B. The children were instructed to lift up the one of the animal pictures to reveal their favourite food. Test pages 2 and 3 (used only in Experiment 1A) were identical, except for the fact that the children were asked whose favourite colour/toy they would like to know.

**Procedure.** The general procedure involved the children having to guess information about the puppets in return for rewards if their guesses were correct. The first time the children encountered the puppets, they had no previous experience with the relevant information and so their guesses were inevitably incorrect. Later on, in another room, they were given the opportunity to seek the information that would enable them to receive the rewards when they encountered the puppets again in the future.

Participants were first led into Room A, identified as “Charlie the Chicken’s room” because of a large poster of a chicken on the wall. The children were sat at a table and the experimenter introduced them to the giraffe puppet “Jamie”. The children were told that Jamie had a favourite drink, and if they could guess what it was then they would receive a sticker from a sticker sheet on the table. Whatever answer they gave, they were told that this was correct and were rewarded with a sticker to enhance their engagement in the main task. The experimenter then introduced the children to “Sammy” the snail, “Ellie” the elephant, and “Terry” the tiger (the order of exposure was counterbalanced across children). The children were invited to guess the snail’s favourite food (strawberries), the elephant’s favourite colour (black), and the tiger’s favourite toy (a puzzle) in return for stickers. The experimenter referred to each favourite thing three times with the following instructions: “This is [name] the [animal], and [name] has a favourite [food/colour/toy]. If you can
guess what [name]’s favourite [food/colour/toy] is then I will give you one of these stickers. So, what do you think [name]’s favourite [food/colour/toy] is?” Following each of these guesses, the children were told that their answers were a good guess but incorrect.

After the questioning procedure, the children were told that they would be going to another room now but would be returning to Charlie the chicken’s room later to talk to the puppets again. The snail, elephant, and tiger puppets were left on the table and the children were taken to Room B. After 15 minutes of unrelated activities, the children were told that very soon they would be returning to Charlie the chicken’s room, and the experimenter invited the children to repeat this fact. The children were then introduced to the booklet. The experimenter showed the children the practice page and demonstrated how to lift up the flaps to reveal the favourite shapes of the cat, the dog, and the rabbit. The children were then told that they could have a turn on the next page, but they would only be able to lift up one picture. The children were asked to confirm how many pictures they would be able to lift up on the next page. The experimenter then opened up the three test pages, and asked the children whose favourite food, toy, and colour they would like to know (of the elephant, tiger, and snail). After the children lifted up the flaps they were encouraged to say the names of the items they revealed. Finally, the children were asked three control questions requiring them to identify which character had a favourite food, colour, and toy.

After this process the children were taken back to Room A. In the same sequence as before, they were invited to guess the favourite things of the snail, elephant, and tiger puppets for stickers. The experimenter scored the children on the correctness of their answers.

**Results and Discussion**

As there were three test pages, each with one correct response and two incorrect responses, the level of chance performance was set at one correct answer out of three. As seen in Figure 2 (left panel), both the four- (M = 2.00, SD = 1.17) and five-year-olds (M = 1.90, SD = 1.25), performed well above chance level on these test questions, *t* (39) = 5.02, *p* < .001, with no significant difference between age groups, *t* (38) = .26, *p* = .796. Exactly half of the children (10 four-year-olds and 10 five-year-olds) answered all three of the test questions correctly, which is much higher than the proportion who would be expected to do so by chance alone (1/27 = 3.7%), *p* < .001. The children answered 87 total control questions correctly, and of the corresponding test questions they answered 76 correctly (87.4%). On the other hand, they answered 33 total control questions incorrectly, and of the corresponding test questions they answered just 2 correctly (6.1%). This suggests that the children were typically using their knowledge about which puppet had which favourite thing when answering the test questions. There were no significant effects involving the order of exposure to the puppets on either the test or control questions, both *F* < 1.60, *p* > .05.
For each child, we calculated a difference score between the number of correct flaps lifted during the test questions and the number of correct answers given upon return to the other room. More negative difference scores indicated greater failure to name the critical, previously seen information at the appropriate occasion. As seen in Figure 2 (right panel), a t-test indicated that 4-year-olds showed significantly more negative difference scores (mean = -.50, SD = .69) than 5-year-olds (mean = -.05, SD = .22), \( t(38) = 2.78, p = .008 \). Of the subset of 20 children who answered all three test questions correctly, five out of ten 4-year-olds failed to name at least one piece of information in the other room, which was significantly more than the number of 5-year-olds (zero out of ten) who failed to name at least one piece of information, Pearson’s \( \chi^2 \) (1, \( N = 20 \)) = 6.67, \( p = .010 \). These results suggest that 5-year-olds may be better than 4-year-olds at encoding, storing, and/or retrieving future relevant information; or at linking past and present experiences.

Although it is tempting to conclude from the above-chance test question performance that the children solved the task using episodic foresight, strategically selecting the information relevant to the anticipated future problem, there remain alternative interpretations. The current procedure met three of Suddendorf and Corballis’ (2010) four behavioural criteria for assessing episodic foresight (it did not meet criterion [iv], because only one type of problem was included), yet there were additional concerns owing to domain-specific features of information seeking. Specifically, the children may have been able to succeed on the test questions using associative memory alone, rather than foresight. They could have done this by encoding the puppet-category pairings of snail-food, elephant-colour, and tiger-toy, and simply using these associations when asked whose favourite food/colour/toy they would like to know—without thinking about the future episode of
revisiting the puppets. Indeed, this may explain why the 4-year-olds often failed to take advantage of the information upon return to the problem.

Experiment 1B modified the paradigm to address the possibility of a simpler associative explanation. This time, each of the three puppets had only a favourite food, such that the puppet-category association was irrelevant if used as a low-level guide to answer the subsequent test question. However, each puppet was also located in a unique spatial context (a coloured box). After initial exposure to the puppets, two of the boxes were removed from the scene and the children were informed that only the one remaining puppet would be spoken to in the future. In this way, the children were encouraged to envision the critical future context at the point of problem exposure. And, later on in the other room, the lifting of the correct flap could not be the result of any puppet-category pairing, but rather required consideration of this specific context—which importantly was not directly referred to when the children were asked which flap they would like to lift.

**Experiment 1B**

**Method**

**Participants.** Eighteen 4-year-olds ($M = 48$ months 24 days, $SD = 20$ days) and eighteen 5-year-olds ($M = 60$ months 10 days, $SD = 31$ days) comprised the sample of the second experiment. Nine of the 4-year-olds and twelve of the 5-year-olds were boys. Each child participated individually with a parent or caregiver present.

**Materials.** The same puppets used in the previous experiment were also used in Experiment 1B. The A4 booklet was also used again, except this time the only pages shown to the child were the practice page and test page 1. The new materials were three large cardboard boxes, each with dimensions of 465mm (width) x 360mm (depth) x 600mm (height). One box was painted red, one blue, and one yellow. The front and back of the boxes were cut in such a way that flaps could be opened to reveal and manipulate the contents inside. The red box contained the snail puppet, the blue box the elephant, and the yellow box the tiger. Another small box containing stickers was used as a potential reward to motivate the children.

**Procedure.** The children were led into Room A, again identified as “Charlie the chicken’s room”. They were shown the three coloured boxes, spread out and arranged in an arc, with the order of the boxes counterbalanced across participants. The children were asked to identify the colour of each box and all children did so correctly. They were then asked to sit in front of the first box (on their left). The experimenter reached into the box from behind and showed the children which puppet was inside. As in Experiment 1A, the children were introduced to the puppet and told that it had a favourite food, and if they could guess that food then they would receive a sticker from the sticker
box. When the children answered, the experimenter told them that it was a good guess but not correct. This procedure was then repeated for the other two boxes and puppets.

After the questioning procedure, the experimenter picked up two of the boxes and placed them out of sight behind a curtain. As he removed each box he informed the children that they would not be playing with that one again. After the two boxes were removed, the experimenter informed the children that he would leave the remaining box (colour counterbalanced across participants) in its place. He informed the children that they would be going to another room now and returning to Charlie the chicken’s room later, but next time they would only sit in front of the remaining box and talk to the puppet inside (the puppet remained visible to the children at this stage as the flaps of the box were left open).

After 15 minutes of unrelated activities in Room B, the children were introduced to the A4 booklet and shown the practice page. Immediately after going through the practice page, the children were informed that (i) very soon they would be going back to Charlie the chicken’s room (no reference was made to the remaining box or the puppet), and (ii) they could lift up only one picture on the next page of the booklet. The experimenter repeated these facts and asked the children to independently generate them to ensure that they understood the task. Finally, the experimenter opened up test page 1 and asked the children whose favourite food they would like to know (the elephant, tiger, or snail). After the children lifted up a picture they were encouraged to say the name of the food. The children were then asked three control questions about which puppet lived in the red box, the blue box, and the yellow box.

The children were then taken back to Room A and asked to sit in front of the remaining box. The experimenter reintroduced the children to the puppet within the box and again invited the children to guess that puppet’s favourite food. If the children had selected the appropriate flap in the other room, they were scored on the correctness of their answer.

**Results and Discussion**

As seen in Figure 3 (left panel), five-year-olds (55.6%) chose the appropriate character on the test question more often than 4-year-olds (27.8%), with the difference significant under a one-tailed test, Pearson’s $\chi^2 (1, N = 36) = 2.86, p = .046$. More importantly, binomial tests indicated that 5-year-olds were significantly more likely than chance (33.3%) to select the appropriate character, $p = .043$, whereas 4-year-olds did not perform significantly different from chance level, $p = .769$.

There was no significant effect of the critical puppet (elephant vs. tiger vs. snail) on children’s test question performance, $F (2, 33) = 1.00, p = .379$, suggesting that performance was not influenced by any inherent biases towards selecting certain puppets over others. Of the children who answered the test question correctly, nine out of ten 5-year-olds and four out of five 4-year-olds recalled the critical information upon re-visiting the other room, with the difference between age groups not
significant, Pearson’s $\chi^2 (1, N = 15) = .29, p = .591$. (It should be noted that information recall was less demanding in this experiment than in Experiment 1A, given that the children only had to encode, store and recall one favourite thing, not three).

![Figure 3. Mean test question performance (left panel) and critical control question performance (right panel) across age groups in Experiment 1B.](image)

Importantly, performance on the critical control question (i.e., about which character lived in the box remaining in the other room) matched test question performance. As seen in Figure 3 (right panel), 5-year-olds (88.9%) performed significantly better than 4-year-olds (38.9%) on this control question, Pearson’s $\chi^2 (1, N = 36) = 9.75, p = .002$. Binomial tests revealed that 5-year-olds performed significantly above chance level, $p < .001$, whereas 4-year-olds did not, $p = .391$. Of the subset of children who answered the critical control question correctly, 5-year-olds performed significantly better than chance on the test question (9 out of 16), $p = .049$, whereas 4-year-olds (3 out of 7) did not, $p = .429$.

Experiment 1B attempted to overcome a potential limitation of the previous experiment by varying the context of the future problem and making the puppet-category association irrelevant. The 5-year-olds performed above chance level on the test question, replicating the results of Experiment 1A and hence substantiating the conclusion that by this age some children are able to select information for a specific future episode. Even though the 4-year-olds did not perform above chance level, however, we cannot rule out the capacity in this younger group, especially considering that their performance on the critical control question also failed to surpass chance levels. If these children could not even recall the box that the appropriate character lived in, then they certainly
could not be expected to choose the appropriate flap for the future episode, regardless of whether they possessed a capacity for future-directed information seeking.

In Suddendorf and colleagues’ (2011) structurally similar two-room task described in the introduction, 4-year-olds were not only able to recall a concrete problem from 15 minutes earlier, but also select an appropriate novel tool that could solve the problem in the future (Suddendorf, et al., 2011). Thus, the difficulty experienced by the 4-year-olds in the Experiment 1B task may have derived from the fact that they had to select from three options (puppets) that they had previously seen, with the memories interfering with each other when they had to recall the critical problem context. And without the puppet-category association to fall back on, they may have simply guessed the answer, even if they potentially possessed the capacity for future-directed information seeking in other contexts. Supporting this case, a recent study from Atance and Somerville (2014) suggests that children’s performance in two-room tasks can be largely explained by their capacity to recall the critical problem.

Alternatively, the performance difference between 4- and 5-year-olds on the test question (and the critical control question) could have arisen due to differences in the use of episodic foresight at the point of problem exposure. As demonstrated by the difference scores in Experiment 1A, 5-year-olds may be better than 4-year-olds at encoding and rehearsing information that will be useful in the future. Thus, in Experiment 1B, the 5-year-olds may have been more likely to recognise the significance of the remaining box and puppet during their initial visit to the room, when they were told that they would return to this context and talk to that puppet again in the future. And in turn, they may have devoted more cognitive resources towards encoding and rehearsing this crucial information, which would have facilitated their later performance on the test question. Nevertheless, the results do not permit this explanation to be disentangled from the simple memory interference explanation presented above, nor from any number of other potential reasons for the 4-year-olds’ failure.

The main conclusion to take away from the Study 1 experiments is that we have demonstrated 5-year-olds’ capacity to engage in future-oriented information seeking in a paradigm that controls for low-level alternative explanations. The ambiguous performance of the 4-year-olds, however, highlights the question of how to disentangle the role of memory from the role of foresight in the behaviour. Study 2 goes some way towards an answer.

**Study 2**

Episodic memory shares much in common with episodic foresight (Suddendorf, 2010), and yet failures of memory do not necessarily rule out a capacity for foresight. Indeed, it has been proposed that episodic memory is often inaccurate (Schacter, 1999) simply as a side effect of our extremely flexible episodic foresight system that can imagine whatever, wherever, whenever
(Suddendorf & Busby, 2003). If we follow Suddendorf & Corballis’ (2010) criterion (iii) for behavioural episodic foresight studies, however, then participants first need to correctly recall a problem from another spatial and temporal context before they can apply their capacity for foresight (as the children were required to do in both experiments of Study 1). In Study 2 we drop this criterion and let children perform the future-oriented behaviour in the same spatial context as the future problem. This has the necessary caveat of introducing a low-level cue for the appropriate behaviour, but it also minimises memory demands and so allows us to disentangle some of the causes of success.

In devising a novel test of future-oriented information seeking with relaxed memory demands, we drew on Miller and colleagues’ ‘selective attention’ task, which was originally developed as a general measure of attention allocation (P. H. Miller, Haynes, DeMarie-Dreblow, & Woody-Ramsey, 1986; P. H. Miller, Seier, Probert, & Aloise, 1991; P. H. Miller & Weiss, 1981; Woody-Ramsey & Miller, 1988). In this task, children are presented with 12 openable boxes – six with a drawing of a cage on the front door and six with a drawing of a house. Underneath the doors with a cage are drawings of familiar animals, and underneath the doors with a house are drawings of familiar household objects. Half of the children are told that their task is to remember which boxes contain which animals, and the other half are told that their task is to remember which boxes contain which household objects. Thus, half of the boxes contain information that will be relevant in the future and half of the boxes contain irrelevant information. The children are then given 25 seconds to open any doors they wish before they are asked to identify the box that contains one specific animal or household object. These studies have uncovered improvements in selective attention (that is, opening doors that will be relevant in the future) over the early schooling years.

In addition to some structural changes (see the method section), we modified this paradigm conceptually to produce a more specific and preschooler-appropriate measure of future-directed information seeking with minimal memory demands. Firstly, in accordance with Suddendorf and Corballis’ (2010) criterion (i), we used only one trial per participant in order to rule out simple learning explanations for the future-oriented behaviour. Authors using Miller and colleagues’ paradigm typically collapse over a number of trials, which may have the effect of grouping children who truly understand the future-directed requirements of the task with others who simply learn to allocate their attention appropriately over the course of the trials.

Secondly, we included a sand-timer that allowed the children to visibly track the amount of time that they had to study before the future test. We reasoned that, if the children knew how much time they had left (and were constantly reminded that this time was decreasing), then they might be more motivated to study the appropriate information and avoid wasting time on irrelevant information. Preschoolers have difficulty understanding temporal terms such as ‘minute’ or
‘second’ (Busby Grant & Suddendorf, 2011), but they find it much easier to comprehend physical instantiations of time such as sand-timers (Bischof-Köhler, 2000; Redshaw & Suddendorf, 2013).

Thirdly, we reduced memory demands further by physically marking the material that would be relevant in the future. Although Miller and colleagues’ task involves few memory demands compared to the two-room task, it still requires the children to remember the instruction about which information is critical. Preschoolers may struggle to maintain this instruction in their limited working memory space (Alloway, Gathercole, & Pickering, 2006) while also engaging in information seeking behaviour.

Finally, our post-studying recall measure tested children on their ability to name all six of the relevant pieces of information, without confining their answers to a set number of options. When children are tested after the studying period in Miller and colleagues’ task, they are typically given the name of one of the relevant pieces of information before being asked to point out its spatial location. Thus, they have an a priori 1/6 chance of simply guessing the correct location without truly knowing it, and an even greater chance if they can rule out locations that they know are definitely incorrect. Our free answer, multi-item recall measure should allow a finer-grained analysis of potential age-based performance differences and the factors related to success.

The aim of Study 2 was to examine preschoolers’ future-directed information seeking skills with minimal memory demands. We administered our modified version of Miller and colleagues’ paradigm to 4- and 5-year-olds. The children were shown two sets of six cards, one set containing information relevant to a future test (on the cards’ opposite sides) and the other set containing irrelevant information. The relevant cards were marked with a puppet to further reduce memory demands, and a one-minute sand timer indicated to the children the time they had to turn over and look at whatever cards they wished. Afterwards, they were tested on their ability to freely name all six pieces of the relevant information.

Method

Participants. The participants in Study 2 were the same 36 children (18 four-year-olds; 18 five-year-olds) that completed Experiment 1B. They completed Study 2 immediately after Experiment 1B. Using these participants had the added bonus of allowing us to check for correlations across tasks.

Materials. The main experimental materials were 12 plastic-coated cards, six with a red border and six with a blue border. The two sets of cards each contained pictures of the same six animals on the front (bird, cat, dog, kangaroo, lion, and lizard). On the back of each red card was a picture of a toy (respectively: teddy bear, dinosaur, ball, doll, car, and puzzle), and on the back of each blue card was a picture of a food (respectively: carrot, orange, banana, apple, strawberry, watermelon). A one-minute sand-timer, used to convey the length of the studying period, was 16cm
high with a diameter of 8cm and filled with green sand particles. The giraffe puppet from Experiment 1A was used to mark the relevant cards.

**Procedure.** The experimenter sat at a table directly across from the children before turning the sand-timer over and instructing them to watch the sand go from one end to the other. In this way the children received pre-experimental experience of the length of the timer’s cycle. Afterwards, the experimenter revealed the cards and placed them in front of the children on a sheet on the table (this made the cards easy to pick up). One group of cards (red or blue, counterbalanced across participants) was placed animal-side up on the left of the sheet in two rows of three, according to the alphabetical order of the animals. The other group of cards was placed to the right of the sheet in the same formation. A standing piece of cardboard was placed between the red and blue cards to emphasise that they belonged to different categories. See Figure 4 for a picture of the experimental set-up from the children’s perspective. The task itself occurred in three phases: *task exposure, studying*, and *test*.

![Figure 4. Depiction of the Study 2 experimental set-up from the children’s perspective. The red and blue cards were placed on opposite sides of the cardboard barrier with their animal sides facing up. The green sand-timer marked how long the children had to turn over the cards and study the items depicted on the other side. The giraffe puppet marked the cards that the children would be playing with once the sand-timer had completed its cycle.](image)

*Task exposure phase.* The experimenter placed the giraffe puppet behind either the red or blue cards (counterbalanced across participants), and informed the children that this meant they
would be playing with this group of cards. The experimenter told the children that on the back of the red/blue cards were pictures of the animals’ favourite toys/foods, and their task was to guess these in return for stickers. After the children guessed each toy/food (incorrectly), the experimenter turned the card over to reveal the correct answer and to ensure that the children knew the name of each toy/food. Afterwards, the experimenter moved the giraffe puppet to the other group of cards and the children also performed the guessing task with these cards. The exposure phase was included so that the children could experience the fact that they did not originally possess the knowledge required to gain the stickers.

**Studying phase.** Immediately after the exposure phase, the experimenter placed the giraffe puppet behind either the red or blue cards (counterbalanced across participants). He told the children that, this time, he would turn the sand-timer over, and when its cycle had completed they would play the same game as before with the cards marked by the giraffe. He reminded the children that they could win stickers if they could guess the favourite toys/foods underneath the appropriate cards. He emphasised that they would not play the game again with the cards that were not marked by the giraffe. The experimenter then told the children that, while the sand was falling, they could turn over and look at whatever cards they liked, and they could keep looking until all of the sand had finished. He emphasised this fact by lifting up and turning one of the red cards and one of the blue cards, before replacing them in their original position. These instructions were then repeated, and the children were asked to confirm which cards they would be playing the game with when the timer had completed its cycle. The experimenter once again reminded the children that they could look at whatever cards they liked, before turning the timer over to signal the beginning of the one-minute studying period.

The children were video-taped during the task, and these videos helped to score the data. We measured how many times children picked up and turned over each card during the studying period (this included instances where they replaced the card in the original animal-side up position, and instances where they replaced it toy/food-side up), the colour of the first card they turned over, and how much time they spent looking at cards of each colour. The time spent looking at the cards was collapsed according to colour, because the children often had multiple overturned cards within their visual field and it was not possible to tell which one they were focusing on. Because of the cardboard barrier between the red and blue cards, however, it was possible to tell which colour cards they were focusing on.

**Test phase.** Immediately after the studying phase, the children were invited to play the guessing game again with the cards that were marked by the giraffe puppet. Each correct answer was rewarded with a sticker, and the children were scored for which individual answers they got correct as well as their total number of correct answers.
Results and Discussion

The data were analysed in two main ways. Firstly, the individual variables were checked for age differences, and for whether 4- and 5-year-olds performed above chance level. Secondly, the variables were entered into a multiple regression with the total number of correct answers in the test phase as the dependent variable, in order to identify which factors were making unique contributions to the children’s test performance.

Analyses of individual variables.

First card preference. Thirteen of the 4-year-olds (72.2%) and fourteen of the 5-year-olds (77.8%) chose a correct card the first time they turned a card over, with separate sign tests revealing that both of these age groups performed above chance level (50%), both \( p < .048 \). There are at least two ways to interpret this result. It may indicate that, at the beginning of the trial at least, children from both age groups had a preference for the information that they knew would be useful in the future. On the other hand, it may simply indicate that the children were cued into choosing a correct card on the first turn by the experimenter’s instructions or the presence of the giraffe puppet (with this cue effect potentially wearing off over time). Nevertheless, despite this interpretational uncertainty, the first card preference variable can still be checked for its independent contribution to the children’s performance on the later test questions (see the multiple regression analysis).

Number of card turns per colour. The number of times that children turned over correct and incorrect cards were entered into a 2 x 2 (Age x Correctness) mixed ANOVA. As seen in Figure 5 (left panel), this ANOVA revealed a main effect of Age, \( F(1, 34) = 7.53, p = .010, \eta^2_p = .181 \), such that 5-year-olds turned over significantly more total cards (\( M = 15.44, SD = 5.28 \)) than 4-year-olds (\( M = 10.39, SD = 5.15 \)). There was also a main effect of Correctness, \( F(1, 34) = 9.47, p = .004, \eta^2_p = .281 \), such that children turned over correct cards (\( M = 8.56, SD = 5.76 \)) significantly more times than incorrect cards (\( M = 4.53, SD = 4.23 \)). These main effects were qualified by an Age x Correctness interaction, \( F(1, 34) = 5.96, p = .020, \eta^2_p = .149 \). Follow-up testing indicated that the 4-year-olds (\( M = 4.94, SD = 4.96 \)) and 5-year-olds (\( M = 4.11, SD = 3.43 \)) did not differ in the number of times that they turned over incorrect cards, \( F(1, 34) = .343, p = .562 \). However, 5-year-olds turned over correct cards (\( M = 11.33, SD = 6.46 \)) significantly more times than 4-year-olds (\( M = 5.78, SD = 3.19 \)), \( F(1, 34) = 10.70, p = .002 \). Five-year-olds turned over correct cards significantly more often than incorrect cards, \( F(1, 34) = 15.22, p < .001 \), whereas 4-year-olds did not, \( F(1, 34) = .203, p = .655 \). These results suggest that the average 5-year-old had a preference for turning over the correct cards during the studying period, whereas the data from the 4-year-olds did not demonstrate such a preference.
Looking time per colour. The amounts of time that children spent looking at correct and incorrect cards were entered into a 2 x 2 (Age x Correctness) mixed ANOVA (data from one 5-year-old were missing). As seen in Figure 5 (right panel), this test revealed a main effect of Age, $F(1, 33) = 6.72, p = .014, \eta^2_p = .169$, such that 5-year-olds spent significantly more time looking at the cards ($M = 44.65s, SD = 11.55s$) than 4-year-olds ($M = 33.28s, SD = 14.08s$). There was also a main effect of Correctness, $F(1, 33) = 9.27, p = .006, \eta^2_p = .219$, such that children spent significantly more time looking at correct cards ($M = 26.14s, SD = 16.55s$) than incorrect cards ($M = 12.63s, SD = 14.34s$). The Age x Correctness interaction did not reach statistical significance, $F(1, 33) = 3.43, p = .073, \eta^2_p = .094$, although post-hoc testing did uncover some revealing effects. Four-year-olds ($M = 13.94s, SD = 16.54s$) and 5-year-olds ($M = 11.24s, SD = 11.93s$) did not differ in the time they spent looking at the incorrect cards, $F(1, 33) = .306, p = .584$. However, 5-year-olds spent significantly more seconds looking at the correct cards ($M = 33.35s, SD = 17.63s$) than 4-year-olds ($M = 19.33s, SD = 12.42s$), $F(1, 33) = 7.46, p = .010$. Five-year-olds spent significantly more time looking at correct cards than incorrect cards, $F(1, 33) = 11.65, p = .002$, whereas 4-year-olds did not, $F(1, 33) = .73, p = .398$.

The results from this measure provide valuable insight into how the children were allocating their limited studying time before the future test. The first thing to note is the relatively large amount of time wasted by the younger children during the studying period. On average, 4-year-olds spent 44.5% of this period not focusing any cards, whereas 5-year-olds did not focus on the cards only 25.6% of the time. Inspection of the testing videos revealed that many of the 4-year-olds looked at the cards for only a brief period, before switching their focus to the falling sand in the
timer and simply waiting for it to complete its cycle. This behaviour, coupled with the lack of a preference for correct cards when they did look at the cards, may suggest either a fundamental lack of understanding of the usefulness of studying relevant information for the future, or a lack of motivation to focus on such information. The 5-year-olds, however, used their time more effectively and also showed a preference for looking at the correct cards, indicating they may have some understanding of the future-oriented usefulness of studying.

**Test phase answers.** An independent samples *t*-test (one-tailed) revealed that 5-year-olds answered significantly more questions correctly during the test phase (*M* = 3.06 out of 6, *SD* = 1.63) than 4-year-olds (*M* = 2.11 out of 6, *SD* = 1.45), *t* (35) = 1.84, *p* = .038 (a one-tailed test is justified here because one would expect performance to improve with age). Despite the age effect, however, this test does not tell us *why* the 5-year-olds outperformed the 4-year-olds on the test questions. In an attempt to answer this question, we entered age and other potentially important variables into a multiple regression.

**Multiple regression analysis.** The dependent variable of the multiple regression was the total number of correct answers during the test phase. The independent variables, entered into the regression simultaneously, included: exact age, the number of times correct cards were turned over, the amount of time spent looking at correct cards in seconds, and whether the child chose a correct card the first time they turned a card over (no = 0, yes = 1). These four predictors significantly explained 51.9% of the variance in children’s performance, *R*² = .519, *F* (4, 30) = 8.09, *p* < .001. The contributions of the individual variables to the model are summarised in Table 1. Only two of the four independent variables added significant unique variance.

**Table 1**

*Standardised Regression Coefficients for Predictors of Children’s Test Question Performance in Study 2*

<table>
<thead>
<tr>
<th>Variable</th>
<th>β</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact age</td>
<td>.16</td>
<td>1.10</td>
<td>.279</td>
</tr>
<tr>
<td>Number of correct card turns</td>
<td>-.31</td>
<td>-1.22</td>
<td>.232</td>
</tr>
<tr>
<td>Time looking at correct cards</td>
<td>.61</td>
<td>2.40</td>
<td>.023*</td>
</tr>
<tr>
<td>Correct first card preference</td>
<td>.42</td>
<td>2.89</td>
<td>.007**</td>
</tr>
</tbody>
</table>

The variable that significantly contributed the most unique variance to the children’s test performance was the amount of time that they spent looking at the correct cards. This suggests that the children may have been actively encoding and rehearsing the information over the time they
were looking at the cards. As described earlier, older children spent more time than younger children looking at the correct cards, which may suggest that their use of this strategy contributed to their higher performance on the test questions. Supporting this view, the significant zero-order relationship (one-tailed) between exact age and total number of correct answers, \( r = .29, p = .045 \), was fully mediated by the time spent looking at the correct cards, \( Z = 2.12, p = .034 \) (Sobel test), such that the direct relationship between exact age and correct answers was not significant, \( t (34) = .30, p = .383 \).

In contrast to the time spent looking at the correct cards, the number of times that children turned over these cards did not contribute significant unique variance to the regression model. This may reflect the fact that some children rapidly turned the cards over many times without actually encoding the information required for the future test. A more effective strategy was to turn the cards over at a moderate pace, with more time spent encoding the future-relevant information.

One final interesting finding was the significant and positive unique contribution of the correct first card preference variable to test question performance. Given that many of the children would have undoubtedly turned over an appropriate first card by chance alone, the strength of this relationship is particularly noteworthy. One interpretation is that the children who turned over an appropriate card first were more likely to understand the future relevance of the studying period than the children who did not, and thus were more likely to be in a future-oriented mindset when looking at the correct cards. In turn, this mindset could have had an effect on memory encoding over and above the effect provided by the sheer amount of time spent looking at the correct cards. A leaner alternative interpretation, however, is that the children were more likely to recall the information they looked at first simply because of a primacy effect (see Murdock Jr, 1962).

**Comparisons with Experiment 1B task performance.** Because the participants in Study 2 were the same as those from Experiment 1B, we were able to check for relationships between the tasks. Age-partialled binary logistic regressions, however, revealed that outcomes on the variables of interest in Experiment 1B’s puppet task (test question performance and critical control question performance) could not be predicted by scores on the variables of interest in Study 2’s task (first card preference, number of correct card turns, time spent looking at correct cards, and number of correct answers), all Wald \( \chi^2 < 1.95, p > .16 \). The lack of significant relationships may have been due to potential power issues, and/or the relative insensitivity of the nominal Experiment 1B measures.

In Experiment 1B, there were 11 children who selected the correct puppet flap, answered the critical control question correctly, and used the information appropriately to obtain the future reward. In Study 2, these 11 children looked at the correct cards (\( M = 26.45s, SD = 16.50s \)) for longer than the incorrect cards (\( M = 11.82s, SD = 13.78 \)), although this difference was not
significant, $t (10) = 1.86, p = .093$. The difference did become significant, however, when one outlier who only looked at the incorrect cards was removed from the analysis, $t (9) = 3.43, p = .008$. This result provides tentative support for the idea that the children who showed the strongest evidence of future-oriented information seeking behaviour in Experiment 1B also showed the behaviour in another context.

**General Discussion**

The current studies provide the first targeted investigation of children’s future-oriented information seeking abilities. The two experiments in Study 1 were based on a modified version of the two-room paradigm previously used by Suddendorf and colleagues (2011) and required children to preferentially seek out specific information that would solve a future problem in a spatially removed context. In Experiment 1A, we found that both 4- and 5-year-olds were more likely than chance to seek information that would be useful in the future. Nevertheless, there was some concern that children could have based their selections on associative memory alone, rather than episodic foresight, which may have explained why the younger children were particularly susceptible to failing to use the information to obtain the future reward. Thus, in Experiment 1B we modified the two-room paradigm to ensure that the correct answer depended on a specific future context. In this experiment, 5-year-olds but not 4-year-olds were more likely than chance to seek the correct information. This result substantiates the claim that many 5-year-olds are truly able to seek information with a specific future episode in mind. Yet, this is not to say that younger children definitely lack this ability, as there may have been many reasons for failure. A common issue in this and other attempts to measure foresight is that problems with foreseeing the future cannot be disentangled from problems with remembering the critical information. Our final study aimed to address this issue by minimising memory demands and allowing children to seek information in the same spatial context in which it would become useful in the future.

Study 2 gave children the opportunity to study relevant information (and irrelevant information) for a future test, using a modified version of Miller and Weiss’ (1981) selective attention paradigm. Five-year-olds as a group demonstrated some level of competence, further substantiating the case that many of them can strategically search for information with a future goal in mind. Four-year-olds, on the other hand, again performed at chance levels, seemingly unaided by the reduction in memory demands. Because this task involved an identical spatial context for the future-directed behaviour and the future problem, there was a chance that the children could have been cued into the appropriate behaviour without necessarily understanding its future relevance (see Suddendorf & Corballis, 2010). And yet, even with this potential cue, the 4-year-olds as a group still did not demonstrate compelling future-oriented studying behaviour, which appeared to explain their poorer performance on the subsequent test questions than the 5-year-olds.
Overall, the main novel contribution of the current studies is the consistent finding that children begin to demonstrate future-oriented information seeking skills by at least the fifth year of life. This developmental pattern falls within the range of other future-oriented behaviours that emerge during the preschool years (Suddendorf & Redshaw, 2013), albeit towards the latter end of this period. As described in the introduction, for example, object selection tasks can be passed by 4-year-olds (Suddendorf, et al., 2011) and perhaps even 3-year-olds (Scarf, et al., 2013), and so future-oriented information seeking may be more cognitively demanding than acting to solve future concrete problems. Indeed, although the 5-year-olds performed above chance levels across all of our tasks, they certainly did not perform at ceiling levels, even in Study 2 when memory demands were relaxed. Future research may wish to examine the reason for this potentially late development, and one possibility concerns the particular type of mental time travel involved.

**Does future-oriented information seeking involve doubly embedded mental time travel?**

Presumably, future-oriented information seeking may emerge later than some other future-oriented behaviours, such as object selection, because of differences in the underlying cognitive processes. In an object selection task, the child must envision themselves encountering the problem in the future before they are able to choose the item that can solve it. In this way, the child is recursively embedding their own future mental perspective within their present experience and using this embedding to guide their behaviour (Corballis, 2011). In a future-directed information seeking task, the child must similarly envision themselves encountering the future problem, and simply doing so may bias them towards preferring the correct information. If they want to perform optimally in the future episode, however, they must also deduce the fact that they will have to rely on their memory to solve the future problem, and hence the information must be encoded, stored, and potentially rehearsed. Under these circumstances, the child is not only embedding a future mental perspective within their present experience, but also embedding a (relative) past mental perspective within the embedded future perspective. This form of mental time travel can be described as *doubly embedded*. The salient differences between 4- and 5-year-olds on each task of the current studies—in the difference scores in Experiment 1A, the test and control question scores in Experiment 1B, and the time spent looking at the correct cards in Study 2—could all potentially be explained by the increased propensity of 5-year-olds to engage in such doubly embedded mental time travel.

Doubly embedded mental time travel may also be involved in prospective memory tasks, in which a person must remember to carry out a certain action given a specific future event or at a specific future time (Einstein & McDaniel, 1990; Kvavilashvili, Kyle, & Messer, 2008). Such action can be triggered automatically by an external cue (e.g., seeing a shop may trigger your latent intention to buy milk), but performance is nevertheless greatly enhanced by internal rehearsal of the
prospective intention before it must be carried out (McDaniel & Einstein, 2000). A propensity to engage in such rehearsal may rely on the doubly embedded understanding that, in the future, one will benefit from the (relative) past mental rehearsal of the intention. Recent evidence suggests that children begin to internally rehearse prospective intentions around age five (Mahy & Moses, 2011), consistent with the developmental pattern seen in the current studies. More broadly, doubly embedded cognition may also begin to emerge around age five in the theory of mind domain (S. A. Miller, 2009; Sullivan, Zaitchik, & Tager-Flusberg, 1994), about one to two years later than singly embedded cognition (Rubio-Fernández & Geurts, 2013; Wellman, Cross, & Watson, 2001).

**Implications, future directions and conclusion**

Regardless of the underlying mechanisms supporting the development of future-oriented information seeking behaviour, the results of the current studies have important applied implications. In the early school years, for instance, we cannot expect children to perform well if they do not understand the future relevance of tasks such as studying and homework—at least when using their own strategies. Although the results suggest that many 5-year-olds do possess some future-oriented understanding of information seeking, the fact that this group did not perform even close to ceiling levels suggests there is much room for improvement. Indeed, many young children may exist in a ‘zone of proximal development’ (Vygotsky, 1978; Wertsch, 1984) in regards to this skill, and so parents and teachers may wish to pay particular attention towards scaffolding their information seeking behaviour with future outcomes in mind. Concurrently, parents and teachers may wish to improve children’s independent skills by explicitly discussing with them the future importance of their information seeking behaviour. Future research may seek to identify the factors relating to individual developmental delays, with the potential long-term goal of producing training programs aimed at improving the skill.

The current studies were the first to directly investigate the development of basic future-oriented information seeking behaviour. Across two structurally distinct domains, 5-year-olds but not 4-year-olds demonstrated an ability to seek and retain information that would be useful in a specific future episode, although even the older children did not perform exceptionally well. This suggests that many, but perhaps not all children will understand the future relevance of tasks such as studying and homework as they are about to begin formal schooling. The mechanisms underlying the emergence of future-oriented information seeking remain unclear, but one prospect is a general ability to engage in doubly embedded mental time travel. Future research could explore this and other possibilities more directly, as a greater understanding of the mechanisms could eventually inform the identification and treatment of children at risk of developmental delays.
References


Chapter 5

The Development of Time-based Prospective Memory in the Presence and Absence of Event-based Cues
Preface

Chapter 4’s study found that many 5-year-old children were able to solve tasks requiring them to seek information for a specific future episode, whereas 4-year-olds struggled on the same tasks when low-level associative explanations were controlled for. One potential reason that I gave for the difference between these age groups was an increased propensity of 5-year-olds to engage in doubly embedded mental time travel—in which they reflect on how their memory will be useful in the future. I suggested that doubly embedded mental time travel may also be involved in prospective memory tasks, in particular when children internally rehearse prospective intentions in order to improve their future memory to perform a particular action.

The following chapter examines 3-, 4-, and 5-year-old children’s capacities on a prospective memory task in which a cue to carry out an intended future action is either present or absent. One might expect doubly embedded mental time travel to be especially important without the cue, because children have to rely more heavily on internal processes to enhance their future memory to carry out the action. Considering the pattern of results in the previous chapter then, one might expect 5-year-olds to perform much better than younger children when the cue is absent.

This chapter has been submitted for publication\(^1\) and at the time of writing it is under peer review. Therefore, many of the concepts and findings mentioned in the general introduction (Chapter 1) and review (Chapter 2) are briefly reiterated. I do not, however, discuss doubly embedded mental time travel, as the data from the previous chapter remain unpublished and I wrote the paper under the framework of the broader prospective memory literature. Instead, I return to the issue of doubly embedded mental time travel in the general discussion (Chapter 8).

\(^1\)Redshaw, J., & Suddendorf, T., & Henry, J.D. (submitted). The development of time-based prospective memory in the presence and absence of event-based cues.
Abstract

Previous time-based prospective memory research, both with children and other groups, has measured the ability to perform an action with the arrival of a time-dependent, yet still event-based cue (e.g., the occurrence of a specific clock pattern), while also engaged in an ongoing activity. Here we introduce a novel means of operationalising time-based prospective memory and assess children’s growing capacities when the availability of an event-based cue is varied. Preschoolers aged three, four, or five years (N = 72) were required to ring a bell when a familiar one-minute sand-timer had completed a cycle under four conditions. In a 2x2 within-subjects design, the timer was either visible or hidden, and either presented as a single task or embedded within a dual picture-naming task. Children were more likely to ring the bell before two minutes had elapsed in the visible-timer and single-task conditions, with performance improving with age across all conditions. Executive function measures independently predicted performance and accuracy in the hidden-timer conditions but not the visible-timer conditions. These results suggest a divergence in the development of time-based prospective memory in the presence and absence of event-based cues, potentially because the latter relies more on executive resources. Our paradigm allows for the assessment of time-based prospective memory in much younger children than previous measures, and it could also be adapted for use with other populations.
Researchers typically distinguish between event-based prospective memory (EBPM), whereby people must act on an intention when prompted by a future external cue (e.g., ‘buy milk next time you are at the shop’); and time-based prospective memory (TBPM), whereby people must act on an intention at a particular future point in time (e.g., ‘get the washing out of the machine in two hours’). Nevertheless, the latter can also be conceived of as an event-based form of memory, as long as there is an external means of tracking time (e.g., ‘get the washing out of the machine when the clock shows 10am’). Indeed, empirical TBPM studies almost universally require participants to perform an action when a clock shows a specific pattern or when an alternative timing device has completed a cycle (for reviews, see Kvavilashvili, Kyle, & Messer, 2008; McDaniel & Einstein, 2007). In the real world, however, TBPM tasks often involve intended actions that need to be carried out at a future time for which no event-based cues are available. You may know that you have to get the washing out of the machine after two hours, for example, but perhaps you did not glance at your watch when turning the machine on. In this case there is no time-dependent event-based reminder to retrieve the washing, and instead you must exclusively rely on your own internal sense of the passage of time and your ability to self-initiate the intended action.

TBPM studies do often include safeguards to ensure that participants are not automatically cued into implementing the intention by the event-based reminder. Many tasks, for instance, require participants to turn their head (e.g., Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995) or press a button (e.g., Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997) in order to look at the timing device. Nevertheless, such paradigms are still conceptually distinct from real-world tasks in which there are no time-dependent event-based cues at all, as in the above example. And so it remains unclear to what degree performance in TBPM tasks is driven by the internal tracking of time and self-initiated implementation of the intention, and to what degree it is driven by the availability of event-based reminders. Furthermore, almost nothing is known about the development of TBPM in the absence of event-based cues in children. Here we provide the first paradigm of TBPM that varies the availability of an event-based cue and is simple enough to be used with very young children (among other populations).

**The Development of Event-based and Time-based Prospective Memory**

EBPM develops during the preschool years, with even 3-year-olds able to succeed at certain tasks (for a review, see Kvavilashvili, et al., 2008). TBPM research, on the other hand, has typically focused on older, school-aged samples (e.g., Ceci & Bronfenbrenner, 1985; Kerns, 2000; Mackinlay, Kliegel, & Mäntylä, 2009). The earliest reported success on a TBPM task is by 5-year-olds, who could sometimes remember to turn a sand-timer over whenever it had completed a cycle, while also playing an unrelated card game (Aberle & Kliegel, 2010). Nevertheless, it should be noted that in this paradigm the visible passage of sand through the timer could act as an event-based
reminder to perform the task. As for other populations, TBPM studies with children do sometimes require the participants to act purposefully in order to see the timing device (Aberle & Kliegel, 2010; Mackinlay, et al., 2009). Interestingly, however, the level of self-initiation required to see the device appears to have no effect on children’s ability to carry out the intended action (Voigt, Aberle, Schönfeld, & Kliegel, 2011). Perhaps this is because, even when the timer requires effort to see, the children can still off-load the need to internally track the passage of time and implement the intention to an external, event-based source. The development of TBPM in the complete absence of time-dependent event-based cues remains almost entirely unexamined.

The only study to assess this ability in children used a school-aged sample of 7- to 12-year-olds, but the authors did not describe their task as a prospective memory task nor did they report whether there was a developmental pattern (Mackinlay, et al., 2009). The children had to tell an experimenter when they thought two minutes had elapsed, while also engaged in an ongoing task that required them to trace tangled lines on a sheet of paper. Although useful for older child participants, however, such tasks would not be appropriate for preschoolers, given their limited understanding of temporal terms such as ‘second’ or ‘minute’ (Busby Grant & Suddendorf, 2011). The very use of such cultural time instantiations also carries the risk that participants will internally count to the crucial time when deciding when to act, rather than relying on their biological clock per se (as was self-reported by many adult participants in a similar task; Waldum & Sahakyan, 2013). A physical instantiation of time, such as a sand-timer, might provide a more child-friendly and controlled means of conveying a specific temporal period (see, e.g., Redshaw & Suddendorf, 2013). Furthermore, because the ongoing tracing task in Mackinlay and colleagues’ study was fully directed by the child, there may have been individual and age-based differences in the degree to which the participants were engaged by the activity (and potentially distracted from carrying out the prospective intention). An experimenter-directed ongoing task, such as picture-naming (see, e.g., Kliegel & Jäger, 2007; Kvavilashvili, Messer, & Ebdon, 2001), would reduce this problem by controlling the rate at which the child performed the activity.

Notably, there exists a large literature assessing the development of ‘time perception’ (Droit-Volet, Delgado, & Rattat, 2006), and some tasks measuring this construct require children to perform an action when they believe a certain amount of time has elapsed. One example is the temporal reproduction task (e.g., Szelag, Kowalska, Rymarczyk, & Pöppel, 2002), in which participants are exposed to a continuous visual or auditory stimulus for a certain period of time, before they are again exposed to the stimulus and asked to press a button when they believe it has appeared for the same amount of time as before. Typically, however, such tasks are administered on their own, rather than with an additional ongoing activity, and so they do not meet the standard definition of a prospective memory task (Ellis & Kvavilashvili, 2000; McDaniel & Einstein, 2000).
Furthermore, the reproduced time period is typically less than 10 seconds, meaning that the original temporal stimulus may be represented in working memory rather than by a long-term internal clock. Finally, because the visual or auditory stimulus is typically available while its temporal length is being reproduced, the children are continuously reminded that they have to match the new stimulus with their internal representation of the original stimulus. It is probably for these reasons that children very rarely fail to press the button in such tasks (unlike in prospective memory tasks where failure is relatively common).

The Current Study

The aim of the current study was to produce a measure that could examine the early development of TBPM in the presence and absence of time-dependent event-based cues. As described earlier, these cues are often unavailable in real-world TBPM situations, and so such a measure could make a valuable novel contribution to the broader prospective memory literature. Our paradigm was designed to be usable with preschool children, while also avoiding issues with previous relevant work, including a reliance on cultural time instantiations and the use of fully child-directed ongoing tasks (or no ongoing tasks at all).

Our basic task required children to ring a bell when a familiar one-minute sand-timer had completed a cycle (or at least before the end of a two-minute trial). We manipulated two variables in a 2x2 within-subjects design. In the visible-timer conditions, the children could rely on the finishing passage of sand as an event-based reminder when deciding when to act. In half of the conditions, however, the timer was covered and the children were required to ring the bell when they thought the sand had finished. In these hidden-timer conditions there was no event-based reminder to perform the action at the appropriate time, nor was there any sensory access to the temporal stimulus (as there is in temporal reproduction tasks).

Besides timer visibility, the other within-subjects variable was task load. In half of the conditions (single-visible and single-hidden) the timer was presented alone and the only task was to ring the bell. These conditions were included to (i) measure task comprehension, and (ii) in the single-hidden condition, provide a measure of time perception that was not embedded within an ongoing task. Because prospective memory requires one to carry out the intended action while engaged in another activity (Ellis & Kvavilashvili, 2000; McDaniel & Einstein, 2000), however, we also included a second task in half of our conditions. In these prospective memory conditions (PM-visible and PM-hidden), the experimenter moved the timer (visible or covered) around a sheet containing 25 pictures, with the children having to name each picture as it was marked by the timer; all the while still remembering to ring the bell at the end of the timer’s cycle. Thus the timer task was embedded within the picture-naming task in much the same way that event-based tasks are
embedded within dual tasks throughout the prospective memory literature (e.g., Kerns, 2000; Kliegel & Jäger, 2007; Rendell & Craik, 2000).

According to conventional models of prospective memory, the appearance of a focal event-based cue (such as that provided by the finishing passage of sand) might be expected to trigger either an automatic retrieval of the prospective intention (McDaniel & Einstein, 2000) or a retrieval requiring only limited executive resources (Smith & Bayen, 2004). Consequently, we hypothesised that children’s performance in the PM-visible condition would be superior to that in the PM-hidden condition. Without the event-based reminder, the PM-hidden condition should impose greater demands upon strategic retrieval processes. McDaniel and Einstein (2000) defined strategic retrieval in terms of recruiting executive resources to monitor the environment for an event-based cue, but this definition could be broadened to include other executive processes, such as internal rehearsal of the future intention, active monitoring of the passage of time, and inhibition of immediate distractions. Executive function shows important developments during the preschool years (Anderson, 2002), particularly between ages three and five (Garon, Bryson, & Smith, 2008), and there is recent evidence for the role of executive function in children’s prospective memory performance (Ford, Driscoll, Shum, & Macaulay, 2012; Mahy & Moses, 2011; Mahy, Moses, & Kliegel, in press). We therefore chose 3-, 4-, and 5-year-olds for our sample, and we included two measures of executive function to examine the predictive value of this construct over the various conditions of the timer task.

Method

Participants

The sample included 72 preschoolers aged within one month of their third, fourth, or fifth birthday (24 from each age group). Fifteen of the 3-year-olds (mean age = 36.31 months, SD = .34), twelve of the 4-year-olds (mean age = 48.34 months, SD = .44), and twelve of the 5-year-olds (mean age = 59.83 months, SD = .45) were boys. All children participated individually with a parent or caregiver present. All children completed all conditions of the timer task, but four did not complete the recognition task or both executive function tasks due to restlessness and were thus excluded from these specific analyses.

Materials

Timer, bell and sock. The sand-timer was 16cm high with a diameter of 8cm and was filled with green sand particles. The length of one cycle was 60 seconds. Other materials included a commercially available call bell and a black sock that could be placed over the timer to conceal the passage of sand.

Dual task picture sheets. The two picture sheets were each in A1 dimensions (84.1cm x 59.4cm) and printed on white satin cloth. Each sheet was divided by gridlines into 25 equally-sized
rectangles in a 5×5 configuration. Each rectangle contained a picture representing an easily identifiable word in the bottom right corner and an empty circle in the top left corner that marked where the timer could be placed (see Figure 1). All 50 images were purchased from the website www.clipart.com to be used royalty free. Each child saw both sheets, one in the PM-visible condition and one in the PM-hidden condition.

Figure 1. Representation of one of the picture sheets used for the prospective memory dual task. Every five seconds the timer (visible or covered by the sock) was placed on top of a new circle and the child had to name the corresponding picture. The second sheet contained 25 different pictures.

Procedure

Timer task. The experimenter sat at a table directly across from the child before turning the timer over and instructing the child to watch the sand go from one end to the other. In this way the child received pre-experimental experience of the length of the timer’s cycle. Immediately afterwards the child was introduced to the bell and asked to practice ringing it, before completing the four timer task conditions consecutively (see below). The single-visible and single-hidden conditions were always administered first and second, ensuring that the child had experience with the basic versions of the prospective task prior to exposure to the dual task. The order of the two prospective memory conditions was counterbalanced across participants. In all conditions the task
was not administered until the child could generate a correct verbal or physical answer to the
question of what they were required to do when (they thought that) the sand had completed a cycle
(i.e. ring the bell). The experimenter scored (i) if the child rang the bell at any time before the two-
minute trial had ended, and if yes, (ii) how long it took the child to ring the bell after the timer was
turned. At the end of each trial, any child who had failed to ring the bell was asked what they were
supposed to do when all of the sand had finished, and was scored for whether they gave a correct
verbal or physical answer.

A blind coder scored a randomly selected 25% of the responses from all four conditions to
check inter-rater reliability. This coder agreed perfectly with the experimenter’s coding of the
performance data, Kappa = 1.00, \( p < .001 \), and almost perfectly with the experimenter’s coding of
the accuracy data, Pearson’s \( r (34) = .995, p < .001 \).

**Single-visible condition.** The experimenter told the child that he would turn the timer over
and that their task was to ring the bell when all of the sand had reached the other end.

**Single-hidden condition.** The experimenter revealed the sock and demonstrated that this
time he would place the sock over the timer before it was turned. The child was told that they were
not allowed to peek under the sock and that their task was to ring the bell when they thought that all
of the sand had reached the other end.

**PM-visible condition.** The experimenter revealed one of the picture sheets and told the
child that he would place the timer next to the pictures and the child had to name each picture as it
was marked by the timer. After some practice at this, the experimenter then told the child that he
would turn the timer as the task began, and the child had to ring the bell (placed to the left of the
sheet) when the sand had reached the other end. The starting picture was either in the top left or
bottom right corner of the picture sheet (as seen by the child), counterbalanced across the PM-
visible and PM-hidden conditions. The experimenter started a digital stopwatch (not visible to the
child) as the task began, and every five seconds moved the timer to a new picture by skipping two
pictures in a horizontal-first direction, such that all 25 pictures were marked by two minutes. If the
child did not name a picture then the experimenter pointed at the picture to remind them of the dual
task, but continued to move the timer every five seconds even if the child still did not name the
picture or if the child had already rung the bell. All children named the large majority of pictures.

**PM-hidden condition.** The experimenter revealed the other picture sheet and explained the
dual task to the child. As in the single-hidden condition, the experimenter demonstrated that he
would place the sock over the timer before it was turned, and the child was told that their task was
to ring the bell when they thought that all of the sand had reached the other end.

**Recognition task.** After completing the final condition of the timer task, the child was
shown 20 cards (half depicting pictures that appeared on the dual task in the prospective memory
conditions; half depicting new pictures) in a pseudo-random order and asked to identify whether they had seen each picture previously.

**Executive function tasks.**

*Day/night task.* In line with Gerstadt, Hong, and Diamond (1994), the child had to say the word ‘day’ when shown a card depicting the moon and stars, and the word ‘night’ when shown a card depicting the sun. The cards were shown eight times each in a pseudo-random order and the child was scored on the number of correct responses out of 16.

*Backwards word span.* This task was modelled on those used by Carlson, Moses and Breton (2002) and Ford and colleagues (2012). The experimenter listed a sequence of one-syllable words and the child’s task was to repeat the words in reverse order. The task included three sequences each of two words, three words, and four words (nine sequences in total), and it concluded when the child failed three consecutive trials. The child was scored for the maximum number of words they could repeat backwards, but if they could not repeat two words backwards they received a score of one.

**Results**

*Timer Task Performance (Did the Child Ring the Bell at All?)*

A graphical summary of the children’s performance in all conditions of the timer task can be seen in Figure 2. Because the dependent variable was nominal (did ring bell vs. did not ring bell) and the experimental design contained a mixture of between-subjects (age) and within-subjects (timer visibility, task load) variables, we entered the data into a Generalised Estimating Equations analysis (Hardin, 2005) for binary responses. There was a significant main effect of Age, Generalised-Score (GS) $\chi^2 (2) = 9.70, p = .008$, such that, across all conditions, 5-year-olds were more likely to ring the bell at any time than 4-year-olds, Wald $\chi^2 (1) = 21.85, p < .001$, who in turn were more likely to ring the bell than 3-year-olds, Wald $\chi^2 (1) = 40.68, p < .001$. Consistent with predictions, there was also a significant main effect of Visibility, GS $\chi^2 (1) = 14.57, p < .001$, and a significant main effect of Task Load, GS $\chi^2 (1) = 5.11, p = .024$, such that the children were more likely to ring the bell in the visible-timer and single-task conditions than the hidden-timer and prospective memory conditions respectively. There were no significant interactions, although inspection of Figure 2 suggests that this may have been partly due to a combination of floor effects for 3-year-olds in the PM-hidden condition (0% success) and ceiling effects for 4- and 5-year-olds in the single-visible condition (97.9% success).
Across all participants and all four conditions, there were 130 occasions (out of 288 total trials) when a child did not ring the bell at all. Only 15 times (across nine participants), however, did children not remember the intention when prompted by the experimenter after the trial (all of these participants were 3-year-olds). This suggests that not ringing the bell was typically due to prospective memory failure rather than retrospective memory failure (see Einstein & McDaniel, 1990), especially among children older than three.

**Timer Task Accuracy**

Because not all children rang the bell in every condition, the accuracy of the children who did ring the bell was analysed separately for each condition. The means and standard deviations of responses in the single-visible condition ($M = 63.40s, SD = 9.70s$), single-hidden condition ($M = 62.33s, SD = 27.79s$), PM-visible condition ($M = 70.46s, SD = 13.97s$), and PM-hidden condition ($M = 51.45s, SD = 14.40s$) suggested that the children who did respond tended to be roughly accurate (albeit with more variance in the single-hidden condition). In line with previous research (Rendell & Craik, 2000; Rendell, Mazur, & Henry, 2009), the children’s accuracy in each condition was classified as either ‘no response’ (did not ring the bell), ‘very early response’ (0-29s), ‘somewhat early response’ (30-49s), ‘on time response’ (50-70s), ‘somewhat late response’ (71-90s), or ‘very late response’ (91-120s). Figure 3 depicts the cumulative percentage of children in each accuracy classification group across each age and condition.
Figure 3. Cumulative percentage of children from each age group in each accuracy classification group across all four conditions.

The children who did ring the bell were also scored on absolute error; that is, the number of seconds from 60 that they rang the bell. The age groups significantly differed in absolute error only in the single-visible condition, $F(2, 65) = 3.65, p = .034$, with 4- and 5-year-olds significantly more accurate than 3-year-olds, $t(65) = 2.66, p = .010$. Potential age effects in the prospective memory conditions may have been hidden due to the relatively small numbers of participants from younger age groups who rang the bell at all.

**Recognition Task**

A one-way ANOVA indicated that performance on the recognition task differed across age groups, $F(2, 67) = 16.71, p < .001$. Follow-up testing revealed that 4- and 5-year-olds ($M = 18.48$ out of 20, $SD = 2.50$) performed better than 3-year-olds ($M = 13.82$ out of 20, $SD = 4.19$), $t(67) = 5.78, p < .001$. Both 4- and 5-year-olds and 3-year-olds performed better than chance (10 out of 20), both $t > 4.27, p < .001$, however, indicating that children from all age groups were paying attention to the dual task as it was administered.

**Age-partialed Relationships between Timer Task Data and Executive Function**

The two executive function measures (backwards word span and day/night task) were checked for a significant positive age-partialed correlation, and this was confirmed, $r(67) = .21, p = .037$, one-tailed. An executive function composite score was then created for each child by summing their Z-scores for the two measures. The individual and composite executive function scores were subsequently checked for age-partialed relationships with the timer task data (using binary logistic regressions for the nominal performance scores and partial correlations for the continuous accuracy scores). These partial relationships are summarised in Table 1. In the single-
hidden condition, performance and accuracy were each significantly predicted by one individual executive function measure and the composite measure. In the PM-hidden condition, accuracy was significantly predicted by backwards word span and the composite measure. Thus, in the single-hidden condition at least, the children who rang the bell tended to have higher executive function scores than the children who did not; and of the children who did ring the bell, those who were more accurate tended to have higher executive function scores. No age-partialled relationships involving the data from the visible conditions were significant.

Table 1

Age-partialled Relationships between Timer Task Data and Executive Function Scores across All Four Conditions

<table>
<thead>
<tr>
<th>Timer Task Measure</th>
<th>Condition</th>
<th>BWS</th>
<th>D/N</th>
<th>EF comp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Single-visible</td>
<td>.00</td>
<td>.37</td>
<td>.04</td>
</tr>
<tr>
<td>(Wald ( \chi^2 ) for binary logistic regression)</td>
<td>Single-hidden</td>
<td>5.15*</td>
<td>2.53</td>
<td>6.03*</td>
</tr>
<tr>
<td></td>
<td>PM-visible</td>
<td>1.93</td>
<td>.30</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>PM-hidden</td>
<td>2.78</td>
<td>.84</td>
<td>2.69</td>
</tr>
<tr>
<td>Accuracy(^a)</td>
<td>Single-visible ((n = 68))</td>
<td>-.02</td>
<td>.12</td>
<td>.06</td>
</tr>
<tr>
<td>(partial ( r ))</td>
<td>Single-hidden ((n = 42))</td>
<td>.25</td>
<td>.59**</td>
<td>.53**</td>
</tr>
<tr>
<td></td>
<td>PM-visible ((n = 37))</td>
<td>.18</td>
<td>.02</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>PM-hidden ((n = 11))</td>
<td>.89**</td>
<td>.21</td>
<td>.77**</td>
</tr>
</tbody>
</table>

*Note. BWS = Backwards Word Span; D/N = Day/night task; EF comp. = Executive Function composite

\(^a\) Accuracy was operationalised as the absolute error (from 60s) multiplied by -1. Only children who rang the bell at any time during the trial were considered in the accuracy analyses.

* \( p < .05 \) ** \( p < .01 \)

In an additional analysis, we considered whether pure time estimation (as measured by accuracy in the single-hidden condition) would predict performance in the PM-hidden condition over and above the contribution of age. A significant partial relationship might suggest that some children failed to ring the bell in the PM-hidden condition simply because they did not think the timer had completed its one-minute cycle by the end of the two-minute trial, rather than because they genuinely lost attention to the future intention. A binary logistic regression, however, did not find a significant effect, Wald \( \chi^2 (1) = .25, p = .618 \).
Discussion

The results of the current study reveal, for the first time, the early developmental pattern of TBPM in the presence and absence of time-dependent event-based cues. In the single-visible condition, when the passage of sand was observable and there was no ongoing dual task, the majority of the 3-year-olds were able to carry out the future intention accurately, suggesting they understood the basic requirements of the prospective task. When the timer was hidden and/or embedded in the picture-naming task, however, most 3-year-olds failed to ring the bell at all and improvements were seen across both of the older age groups. Given that the children who did not ring the bell were typically still able to recall the intention when prompted by the experimenter after the trial, the increase in performance between ages three and five appears to have been driven by prospective memory improvements rather than retrospective memory improvements (see Einstein & McDaniel, 1990). This finding is consistent with other recent results indicating an increase in prospective memory abilities throughout the preschool years (e.g., Causey & Bjorklund, in press; Mahy, et al., in press; Walsh, Martin, & Courage, in press).

Of more general interest, however, was the novel main effect of timer visibility. In the PM-visible condition, over half of the 4-year-olds and nearly all of the 5-year-olds remembered to ring the bell, extending previous work showing that TBPM tasks can be passed by 5-year-olds when event-based cues are available (Aberle & Kliegel, 2010). In the PM-hidden condition, on the other hand, even 5-year-olds struggled, with less than half remembering to ring the bell. Overall, these results suggest that TBPM develops during the preschool years, with performance lagging when event-based cues are unavailable. This finding stands in contrast to previous results showing no performance lag when event-based cues merely require more effort to see (Voigt, et al., 2011).

One potential reason for the visibility effect is that, in both of the hidden conditions, many children were intending to ring the bell at some stage, but simply did not think the timer had completed its one-minute cycle prior to the end of the two-minute trial. This explanation seems unlikely, however, given that the children who did respond formed roughly normal accuracy distributions centred close to 60 seconds, just as they did in the visible conditions. Furthermore, the children’s accuracy in the single-hidden condition (as a proxy for pure time estimation ability) did not predict their performance in the PM-hidden condition. Therefore, it appears more likely that the children who did not ring the bell in the PM-hidden condition genuinely lost attention to the prospective intention, despite clearly demonstrating their competence at the basic task in the single-visible condition.

Perhaps the most reasonable explanation for the children’s poorer performance in the hidden conditions is that time-based tasks rely more heavily on the strategic component of prospective memory (McDaniel & Einstein, 2000) when there are no event-based cues available. Without the
sand reminding them that they needed to ring the bell, the hidden conditions may have required the children to recruit additional executive resources to drive internal maintenance of the future intention, monitoring of the time until the future action was required, and inhibition of immediate distractions. Supporting this view, the children’s performance on executive function tasks predicted their performance and/or accuracy in the hidden conditions but not the visible conditions. Indeed, the lack of any executive function effects in the PM-visible condition, in contrast to the strong effects in the single-hidden condition, may suggest that the dual task itself was not as demanding of executive resources as the requirement to cognitively maintain the future intention and monitor the time left until the future action was required. The current study may therefore complement recent work showing that future-oriented cognition (e.g., Atance & O’Neill, 2005; Suddendorf, Nielsen, & Von Gehlen, 2011) and cognitive monitoring (Mahy & Moses, 2011) emerge during the preschool years, and it may also highlight the importance of executive function in the mental representation of and preparation for future events (see Suddendorf & Corballis, 2007; Suddendorf & Redshaw, 2013). Nevertheless, because of the ceiling and floor effects evident in the data, we do make these suggestions with caution.

Regardless of its causes, the visibility effect clearly suggests that TBPM is more difficult in the absence of time-dependent event-based cues. Thus, on other TBPM measures, which nearly all contain event-based cues, performance may be partly driven by EBPM. Many real-world TBPM tasks do not include event-based cues, and so our paradigm, or adapted versions of it, may prove useful for future studies that wish to examine TBPM in isolation. Such work could concentrate on children or other populations among whom TBPM is thought to be impaired (see, e.g., Altgassen, Williams, Bölte, & Kliegel, 2009; Costa, Peppe, Caltagirone, & Carlesimo, 2008; Henry, MacLeod, Phillips, & Crawford, 2004; Henry, Rendell, Kliegel, & Altgassen, 2007; Kliegel, Ropeter, & Mackinlay, 2006; Rendell, Mazur, et al., 2009). Given that picture-naming may be too simple as a dual task for adult participants, these studies could instead use other items on the board, such as basic arithmetic problems. Another potential task modification could be the inclusion of a delay between the delivery of the prospective instructions and the beginning of the dual task, thus increasing the difficulty of maintaining and retrieving the prospective intention. Many studies with young children do not include such a delay (e.g., Aberle & Kliegel, 2010; Ford, et al., 2012; Mäntylä, Carelli, & Forman, 2007; Rendell, Vella, Kliegel, & Terrett, 2009), although it is standard practice with older populations (Ellis & Kvavilashvili, 2000).

In conclusion, our paradigm provides the first measure of TBPM that varies the presence of a time-dependent event-based cue and can be administered to very young children. The results suggest a divergence in the development of TBPM in the presence and absence of event-based cues, potentially because the latter relies more on the strategic, executive component of prospective
memory. Tasks such as ours may be used to compare TBPM and EBPM under various conditions and with various populations.
References


Chapter 6

When can Children Spontaneously Prepare for Alternative Future Event Outcomes?
Preface

The previous three chapters involved studies assessing children’s capacity to engage in novel future-oriented behaviours. In each of these studies children had to consider a single future event and engage in behaviour that would help them to perform optimally when that event arrived. The studies uncovered developments at various times throughout the preschool years, as children become increasingly competent in their episodic foresight capacities.

The following chapter’s study gives 2-4 year-old children the opportunity to not only prepare for a single future event, but also consider and prepare for multiple possible outcomes of that event. I develop a minimalist paradigm to assess this capacity, with negligible language demands and no complex intermediate steps between the behavioural preparation and the future outcome. Because of its simplicity, this paradigm can also be administered to non-human primates, and so I additionally include a preliminary test of three adult chimpanzees.

This chapter has been prepared for eventual submission for publication\(^1\). Therefore, many of the concepts and findings mentioned in the general introduction (Chapter 1) and review (Chapter 2) are briefly reiterated. Because the experimental paradigm and results may be of broad interest beyond the developmental psychology literature, I have followed the preferred format of many general science journals by placing the materials and methods section at the end of the main article.

\(^1\)Redshaw, J., & Suddendorf, T. (to be submitted). When can preschool children spontaneously prepare for alternative future event outcomes?
Abstract
Humans possess the remarkably flexible ability to prepare for multiple, mutually exclusive versions of single future events. When this capacity develops in children, however, remains largely unknown. We tested preschool children (N = 90) on a minimalist behavioural paradigm in which they were given the opportunity to catch a ball that was dropped into a forked tube with one opening at the top but two openings at the bottom. Few 2-year-olds, many 3-year-olds and most 4-year-olds spontaneously covered both bottom openings of the tube the first time they prepared to catch the ball, with performance improving over subsequent trials across age groups. This pattern of results suggests that many children aged three years and older can insightfully prepare for alternative versions of immediate future events, whereas the success of some younger children on later trials may simply reflect trial-and-error learning. We also administered a preliminary test of our paradigm to three adult chimpanzees, with none of them spontaneously covering both bottom openings but one learning to reliably do so after many trials. Spontaneously passing our task may typically require a capacity to form metarepresentations, which enables agents to reflect on their representation of a single version of a future event and to understand that this representation could be incorrect.
Much of humanity’s success on this planet can be attributed to our ability to envision, prepare for, and actively shape specific future events (Suddendorf & Corballis, 1997, 2007). Yet, this is not to say the human mind contains some sort of crystal ball that can precisely foretell how the future will unfold. Many future events are difficult to predict with any degree of certainty. We often believe we are better at predicting events than we actually are (Vallone, Griffin, Lin, & Ross, 1990), even though our histories are littered with examples in which we failed to correctly anticipate the future and thus failed to avoid problems or take advantage of opportunities. One powerful way in which humans can prudently deal with uncertainty about the future is to ‘hedge our bets’ and prepare for multiple (even mutually exclusive) versions of upcoming events. We may prepare for a picnic in the sun, for example, but we may also pack an umbrella in case the weather changes. Other people’s future behaviour is particularly difficult to predict, and so we may often devise a Plan B (and C) for social situations. We may even prepare for relatively ambiguous alternative futures, for instance when we buy insurance to protect against misfortunes. Despite the importance of the capacity to consider and prepare for alternative future events, however, little is known about when and how it develops in children.

Here we show that even preschool children have an ability to insightfully act for mutually exclusive versions of the future. To examine the early development of this capacity, we created a very simple task that allowed children to spontaneously prepare for two potential outcomes of a single undetermined future event. We constructed a novel forked tube apparatus that had one opening at the top but two openings at the bottom (see Figure 1). The experimenter could drop a ball into the top of the tube and surreptitiously control which bottom opening it would fall from (in a pseudorandom order). After six observation trials, the children were invited to catch the ball for twelve trials, and if they failed to do so it fell on a ramp and rolled out of reach. We were interested in whether the children ($n = 90; 18$ each from age groups $2, 2.5, 3, 3.5,$ and $4$ years) would cover one or two bottom openings (with two hands) when preparing to catch the ball (see Figure 1, left panel). See the Materials and Methods section for more detailed procedural information.
Figure 1. Depiction of the experimental task given to children (left panel) and chimpanzees (right panel). Participants had the opportunity to cover one or both bottom openings of the forked tube when preparing to catch a ball/grape that would be dropped into the top opening. The child is covering both bottom openings, whereas the chimpanzee is only covering one.

Our task involves an immediate future event in which the behavioural preparation and future outcome occur in the same context. This has the advantage of not conflating the central capacity of interest—preparing for alternative future outcomes—with other capacities like imagining an appropriate spatial and temporal context for the alternative outcomes (Suddendorf & Corballis, 2007; Suddendorf & Redshaw, 2013), which may be difficult to control. The task also takes advantage of a natural behavioural response, given that even 2-year-olds are adept at using both hands to collect appealing objects. And interestingly, because our paradigm has minimal language demands, it can also be adapted for use with non-human primates—which may eventually provide some insight into the evolution of the capacity. Indeed, any primate with two functional hands and a motivation to obtain food can be tested relatively straightforwardly. We therefore conducted an additional preliminary test in which three adult chimpanzees were given the opportunity to catch grapes dropped into the tube (see Figure 1, right panel).

We were particularly interested in whether the participants would spontaneously cover both bottom openings of the forked tube on the first trial in which they were given the opportunity to do so. Success on the first trial indicates insight into the particular contingencies of the task, whereas success on later trials might also be explained through simple trial-and-error conditioning.
Specifically, each time the item was not caught with the one-hand strategy, the participants might be more motivated to try a different behaviour, and the partial reinforcement of each hand may ultimately lead to the optimal two-hand strategy emerging. We included additional trials to determine whether the two-hand response would be learned eventually, and also to show that the physical coordination required for such a response was within the capacity of the participants.

Figure 2 shows the cumulative number of children who covered both bottom openings of the tube for the first time over all twelve trials. None of the 2-year-olds, few 2.5-year-olds, many 3- and 3.5-year-olds, and most 4-year-olds used this strategy on the first trial. A significant Cochran-Armitage $\chi^2$ test revealed that the children’s use of the two-hand strategy on the first trial increased linearly with age, $\chi^2 (1) = 25.74, p < .001$. Follow-up Pearson’s $\chi^2$ tests revealed that the 4-year-olds were significantly more likely to use the two-hand strategy on the first trial than the 3- and 3.5-year-olds, $\chi^2 (1) = 4.58, p = .032$, who in turn were significantly more likely to use this strategy on the first trial than the 2- and 2.5-year-olds, $\chi^2 (1) = 13.57, p < .001$. This pattern of first-trial results suggests that the ability to insightfully prepare for multiple potential outcomes of a single future event emerges during the third and fourth years.

**Figure 2.** The cumulative number of children from each age group who covered both bottom openings of the pipe for the first time across all twelve trials.

Despite their poor spontaneous performance on the first trial, however, Figure 2 shows that many 2- and 2.5-year-olds adopted the two-hand strategy at least once over the later trials. And nearly all 3-, 3.5-, and 4-year-olds had used the two-hand response at least once by the end of the
experiment. Because the dependent variable was nominal (one-hand strategy vs. two-hand strategy) and the experimental design contained a mixture of between-subjects (age) and within-subjects (trial) variables, we entered the trial-by-trial data into a Generalised Estimating Equations analysis (Hardin, 2005) for binary responses. This analysis revealed a significant main effect of Age Group, Generalised-Score (GS) $\chi^2 (4) = 33.45, p < .001$, with a linear contrast showing that, across all trials, children were more likely to use the two-hand response with increasing age, Wald $\chi^2 (1) = 143.27, p < .001$. The analysis also revealed a main effect of Trial, GS $\chi^2 (11) = 24.85, p = .010$, with a linear contrast showing that children became more likely to use the optimal two-hand response over time, Wald $\chi^2 (1) = 132.55, p < .001$. There was also a significant Age Group x Trial interaction, GS $\chi^2 (44) = 69.30, p = .009$, suggesting that the effect of age changed over trial (as one might expect with 3-, 3.5-, and 4-year-olds approaching ceiling level before the end of the experiment). The later-trial success of many 2- and 2.5-year-olds demonstrates that the two-hand response was within their behavioural repertoire, although the general lack of initial success suggests that this strategy was typically not insightful but rather conditioned in these groups.

Interestingly, not all of the children who adopted the two-hand strategy maintained it across later trials. Figure 3 shows that many 2- to 3.5-year-olds (but no 4-year-olds) regressed to the less efficient one-hand strategy on at least one later trial. Of the children who used the two-hand strategy at least once ($n = 67$), regressing to the one-hand strategy was significantly less likely among 4-year-olds (0 out of 17) than among the younger children combined (19 out of 50), Pearson’s $\chi^2 (1) = 9.02, p = .003$, even though 4-year-olds tended to adopt the two-hand strategy much earlier than younger children. This pattern of results substantiates the claim that most 4-year-olds and some 3-year-olds were solving the problem insightfully, whereas many of the younger children were weakly conditioned into using the optimal response through trial-and error learning and thus remained susceptible to using the one-hand strategy on some trials.
Unlike the older children, none of the three chimpanzees used the optimal two-hand strategy on their first trial. Indeed, only one (Holly) used it at all on any of the first twelve trials. She used the two-hand response on trials 9 and 11, but regressed to using the one-hand response on trials 10 and 12, much like many of the younger children. Because of the chimpanzees’ poor performance over the initial trials, we were interested in whether they could eventually learn to consistently employ the two-hand strategy over several extra trial blocks.

The performance of all three chimpanzees across all trials is summarised in Figure 4. All subjects were given at least 24 extra trials (blocks 2 and 3) in which the grape fell from both sides of the tube in the regular pseudorandom order. Two of the chimpanzees (Holly and Cassie) showed no evidence of using the two-hand response during these extra trials, although the other subject (Samantha) used the response once in both blocks (on trials 15 and 36). Because of this, we continued to administer the trials in the regular pseudorandom order to Samantha, and by the end of the first day of testing (trial block 5) she was using the optimal two-hand response on every trial. When we tested her the following morning (trial block 6), however, she regressed to using the one-hand strategy, although by that afternoon (trial block 7) she was again using the two-hand strategy on all trials. Such a response pattern—an initial appearance of the target behaviour after many unsuccessful trials, followed by brief regression, spontaneous recovery and eventual maintenance—is consistent with simple operant conditioning principles (Staddon & Cerutti, 2003) rather than insightful behaviour. Nonetheless, Samantha’s results do show that chimpanzees can learn to reliably use the two-hand response. Holly and Cassie did not learn to reliably use this response,
even when we removed all reinforcement of the one-hand response by forcing the grape to come out of the uncovered opening (see Figure 4, and Materials and Methods for supplementary results).

Figure 4. Chimpanzees’ use of the one-hand and two-hand strategies across multiple blocks of twelve trials. In the “opposite” trials, the experimenter forced the grape to come out of the uncovered hole if the chimpanzee used the one-hand response, rather than using the regular pseudorandom order. The two trials marked with an “X” indicate where Holly refused to attempt to catch the grape after repeated unrewarded one-hand responses.

Contrary to the responses of Samantha and the 2-year-olds, many children aged three years and older spontaneously prepared for both potential outcomes of the event on the first trial. Furthermore, most 3-year-olds and all 4-year-olds from this sub-sample maintained that response over every subsequent trial. This pattern of results suggests that, among these children, the two-hand response was underscored by insight into the particular contingencies of the problem. In other words, they understood that the future location of the ball was uncertain and were able to prudently prepare for two mutually exclusive possibilities.

The results of the current study contrast with two previous studies of children’s ability to prepare for alternative future event outcomes, which found strong positive evidence for the behaviour only during the fifth year (Beck, Robinson, Carroll, & Apperly, 2006; Robinson, Rowley, Beck, Carroll, & Apperly, 2006). Unlike our minimalist task, however, the tasks used in these studies relied heavily on language comprehension and included complex intermediate steps between the preparatory behaviour and the future outcome. Our results more comfortably place the capacity to insightfully prepare for alternative futures on a similar developmental trajectory to other future-oriented behaviours (McCormack & Atance, 2011; Suddendorf & Moore, 2011; Suddendorf & Redshaw, 2013), such as the abilities to delay gratification (Garon, Longard, Bryson, & Moore,
2012; Mischel, Shoda, & Rodriguez, 1989; Moore, Barresi, & Thompson, 1998), to select an appropriate object to solve a future problem (Russell, Alexis, & Clayton, 2010; Scarf, Gross, Colombo, & Hayne, 2013; Suddendorf, Nielsen, & von Gehlen, 2011), to save resources for the future (Metcalf & Atance, 2011), and to learn rules that must be applied in the future (Ford, Driscoll, Shum, & Macaulay, 2012; Kliegel & Jäger, 2007; Mahy & Moses, 2011).

The improvements on our task with increasing age may have been driven by developments in various cognitive components of foresight that typically occur around the third and fourth years (Suddendorf & Redshaw, 2013). One fundamental component is the capacity to form metarepresentations, which allows an agent to reflect on the relationship between their representation of a given event and the event itself (Perner, 1991; Pylyshyn, 1978). An effective way to solve our task, for instance, would be to reflect on a representation of the ball coming out of one bottom opening of the tube, recognise that this representation of the event could be incorrect (metarepresentational insight), and simultaneously prepare for the alternative version of the same event. The capacity to form metarepresentations is also involved in passing explicit false-belief tasks (Wimmer & Perner, 1983), in which a child must recognise and act on the fact that another agent can represent the world incorrectly. Children typically begin to pass such tasks around four years of age (Wellman, Cross, & Watson, 2001), although many pass aged three when language and working memory demands are simplified as much as possible (Rubio-Fernández & Geurts, 2013). This pattern of results is consistent with the pattern seen in the current study, supporting the possibility that both tasks typically rely on a capacity for forming metarepresentations. It must be noted, however, that our task should not be considered an acid test of metarepresentational insight, because it remains possible that a child could spontaneously pass through simpler means (Perner, 2012; Perner, Rendl, & Garnham, 2007). Nonetheless, the overall pattern of results does suggest that a fundamental shift in the representational mind occurs typically during the middle preschool years (Perner, 1991; Suddendorf, 1999).

An exciting secondary finding was the failure of three adult chimpanzees to spontaneously use the two-hand response, with only one subject eventually passing reliably in a manner consistent with simple trial-and-error learning. Given the small sample and the difficulties associated with identifying reasons for failure, interpretation ought to remain cautious. Nevertheless, the results do raise the intriguing possibility that humans’ closest extant relatives cannot insightfully prepare for alternative futures, which would suggest that this ability evolved after the split of the human and chimpanzee lineages approximately 6-8 million years ago (Langergraber et al., 2012; Prado-Martinez et al., 2013). If spontaneous success on our task does typically rest on a capacity for forming metarepresentations, then a general inability of chimpanzees to pass in this manner would be consistent with their failure to pass behavioural false-belief tasks (Call & Tomasello, 1999;
Krachun, Call, & Tomasello, 2010; Krachun, Carpenter, Call, & Tomasello, 2009), and with the proposal that metarepresentations may be uniquely human (Redshaw, in press; Suddendorf, 1999).

In conclusion, we have shown that many 3-year-olds and most 4-year-olds are able to spontaneously prepare for two mutually exclusive versions of a single undetermined future event. We obtained very limited evidence for this capacity in younger children and no evidence in a small sample of chimpanzees. Future research may seek to narrow down the cognitive components required to pass our task. Whatever its cognitive underpinnings, however, spontaneous passing of our task is a simple and straightforward demonstration that an individual can take two potential versions of the future into account to prudently prepare for what cannot be known for certain.
Materials and Methods

Methodology for children

Participants. Ninety preschool children participated in the experiment at the University of Queensland in Brisbane, Australia, between August 2013 and February 2014. The children were recruited from a database of parents and caregivers who had previously expressed an interest in participating in early childhood psychology experiments. All children participated individually, with a caregiver present in the experimental room at all times. There were five age groups (2-year-olds, 2.5-year-olds, 3-year-olds, 3.5-year-olds, and 4-year-olds), each consisting of 18 children aged within two months of the respective group label. The descriptive statistics for each age group can be seen in Table S1 below.

Table S1

<table>
<thead>
<tr>
<th>Age group</th>
<th>Gender split (M/F)</th>
<th>Mean age (months)</th>
<th>SD age (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-year-olds</td>
<td>10/8</td>
<td>24.30</td>
<td>.85</td>
</tr>
<tr>
<td>2.5-year-olds</td>
<td>10/8</td>
<td>30.38</td>
<td>.77</td>
</tr>
<tr>
<td>3-year-olds</td>
<td>10/8</td>
<td>36.63</td>
<td>.77</td>
</tr>
<tr>
<td>3.5-year-olds</td>
<td>8/10</td>
<td>41.97</td>
<td>.33</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>9/9</td>
<td>48.78</td>
<td>.65</td>
</tr>
</tbody>
</table>

Apparatus. The main “forked tube” apparatus (see Figure S1, left and middle panels) consisted of a number of PVC pipe fittings connected in such a way that the apparatus had one opening at the top but two openings at the bottom. The top arm of the tube was cylindrical, approximately 50cm long, and approximately 9cm in diameter. Inside the top opening was a funnel fastened with tape, such that a ball (or grape) dropped into the tube would fall in approximately the same place inside the tube every time. Approximately 3cm underneath the funnel, on the inside of the tube, was a wooden platform approximately 8cm long x 3cm wide, fastened to the inside of the tube with a wingnut screw accessible on the outside. Underneath the wooden platform was a fixed piece of cardboard the same width as the inner diameter of the tube and running the rest of the length of the top arm. The wingnut screw could be turned to rotate the wooden platform in such a way that a dropped item would be forced to run down one side of the cardboard, on either the left or
right side of the tube. The bottom of the top arm of the tube connected to an inverse T-section, with each side of the T attached to a 90° curved pipe fitting. At the bottom of each curved fitting was a narrowing fitting that allowed children to entirely cover each bottom opening of the apparatus with their hands. Once constructed, the apparatus allowed the experimenter to drop a ball into the top opening with full control over which bottom opening the ball would fall from.

Another, more basic pipe apparatus used only in the practice phase of the experiment was the “straight tube”. This apparatus consisted of a single cylindrical pipe, approximately 50cm long with a diameter of approximately 9cm, with the bottom opening connected to a narrowing fitting that allowed children to entirely cover the opening with their hands (see Figure S1, right panel). The balls dropped into the straight and forked tubes were spherical polybutadiene “bouncy balls” approximately 3cm in diameter. The “ramp” that the balls rolled down was a piece of plywood approximately 90cm long and 60cm across. This ramp was leaned against the top of a small wooden chair approximately 45cm high, such that an uncaught ball would land on the ramp and roll away from a child standing behind the chair.
Procedure.

**Practice phase.** The children were asked to stand behind the wooden chair, while their caregivers were asked to sit on the other side of the room. The experimenter introduced the children to the straight tube and the bouncy balls, before asking the children to place their hands behind their back. The experimenter then stood directly above the ramp and dropped three balls into the straight tube one at a time, such that each ball fell onto the ramp and rolled away from the children. The children were then invited to catch the next ball, with the experimenter demonstrating how to completely cover the narrow opening at the bottom of the straight tube with a single hand. The experimenter continued dropping balls into the straight tube until the children had caught three consecutively, which they were encouraged to place into a small bucket at their feet.

The experimenter then introduced the children to the forked tube, and again asked them to place their hands behind their back and observe. The experimenter again stood directly above the ramp and dropped six balls into the tube such that they fell onto the ramp and rolled away from the children. During this procedure, the experimenter surreptitiously turned the wingnut screw (not visible from the children’s perspective) such that the ball came out of the bottom openings of the tube in the following pseudorandom order: right, left, left, right, left, right (from the experimenter’s perspective). The experimenter touched the screw between each trial, whether he turned it or not, such that the children had no obvious external cue as to which side of the tube the ball would fall from on any given trial.

**Test phase.** After the six observation trials with the forked tube, the experimenter told the children that they could try to catch the balls again. He told them that they could do whatever they wanted when trying to catch the balls (without explicitly mentioning the opportunity to use two hands), and that if they caught lots of balls they would receive stickers in return. The experimenter then stood above the ramp and dropped balls into the forked tube for 12 trials, forcing them to come out of the bottom openings of the tube in the following pseudorandom order: right, left, left, right, left, right, left, right, left, left, right, right (from the experimenter’s perspective). Again, the experimenter touched the wingnut screw between each trial, whether or not he turned it to change the bottom opening that the ball would fall from. Individual trials immediately followed each other, as long as the children were still interested in participating. Children were encouraged to place caught balls into the bucket at their feet, and all children were rewarded with stickers at the end of the experiment. All sessions were videotaped, and for each trial the children were scored for whether they covered one or two bottom openings in their preparation to catch the ball.

**Methodology for chimpanzees**

**Participants.** Three captive born and raised adult chimpanzees (one male, two female) participated in the experiment at Rockhampton Zoo in Rockhampton, Australia, between 4 and 6
February, 2014. “Cassie” is a male aged 42 years at the time of testing, who had previously participated in experiments on object permanence understanding (Collier-Baker, Davis, Nielsen, & Suddendorf, 2006; Collier-Baker & Suddendorf, 2006), inferential reasoning (Nielsen, Collier-Baker, Davis, & Suddendorf, 2005), imitation recognition (Nielsen, et al., 2005), and mirror and video self-recognition (unpublished). “Holly” is a female aged 25 years at the time of testing, who had previously participated in experiments on object permanence understanding and video self-recognition (unpublished). “Samantha” is a female aged 30 years, who had not previously participated in experiments. The chimpanzees are unrelated and live together in a large zoo enclosure with separate living and sleeping quarters. They are provided with food, medical care and enrichment activities at various times throughout the day by zookeepers. Water was available to the chimpanzees at all times throughout the experiment.

**Apparatus.** The materials used with the chimpanzees were identical to those used with the children, with a few exceptions. Instead of bouncy balls, the items dropped into the tubes were grapes. The grapes tended to be smaller in diameter than the bouncy balls, and so the narrowing fittings of the forked tube openings were changed from “stepped” to “smooth” to prevent the grapes from getting caught in the inner steps of the tube (see Figure 1 in the main text). The plywood ramp was used when testing Holly and Samantha, but not Cassie, because of the different settings in which they were tested (see below for more information).

**Experimental setting.**

*Holly and Samantha.* The experimental setting for Holly and Samantha is depicted in Figure 1 of the main text. The plywood ramp was placed on the experimenter’s side of a meshed wall, with one end sitting on top of a metal bar such that it was raised approximately 20cm from the ground. Approximately 30cm above the ramp were two large holes in the mesh that each allowed the chimpanzees to comfortably put one hand through to the side containing the ramp. These holes were horizontally separated by approximately the same distance that separated the two bottom openings of the forked tube, such that during the experiment the chimpanzees were easily able to cover both bottom openings (with two hands) if they wished. The ramp was raised high enough such that any uncaught grape would roll away from the chimpanzees before they had a chance to grab it. While each chimpanzee was being tested individually, the other two chimpanzees were distracted with attention from research assistants in other areas of the enclosure.

*Cassie.* The experimental setting had to be altered for Cassie because he refused to sit in the area where Holly and Samantha were tested (apparently for fear of attack). To reduce his apprehension, we locked Cassie away from the other chimpanzees in the sleeping area of the enclosure. This area contained a meshed wall with a gap at the bottom of approximately 10cm, such that Cassie was able to comfortably place both of his hands through the gap. On the outside of
this wall was a drop to the ground of approximately 120cm, such that a researcher could stand and hold the tube in front of Cassie during the experiment (see Figure S2). The plywood ramp was unnecessary in this setting, as any uncaught grapes simply fell to the ground on the researcher’s side of the wall before Cassie could grab them.

Figure S2. Experimental setting for Cassie. He covered a single bottom opening with his right hand on every forked tube trial.

**Procedure.** The procedure was broadly similar to that used with the children. Like the children, the chimpanzees first each received three observation trials and three successful practice trials with the straight tube. They then each received six observation trials and twelve (initial) test trials with the forked tube, with the grape falling out of the bottom openings in the same pseudorandom orders that were used with the children. During the observation trials, the tube was held far enough from the meshed wall that the chimpanzees could not reach through and catch the grape. On test trials, however, the tube was held against the meshed wall such that the chimpanzees could easily cover both bottom openings if they wished. As for the child participants, the experimenter touched/turned the wingnut screw (not visible to the chimpanzees) after every trial, such that there were no obvious external cues as to the bottom opening that the grape would fall from. On a few test trials, the grape bounced off a chimpanzee’s hand and fell out of reach even after they had covered the correct bottom opening of the tube. On these trials the chimpanzee was given the grape so as to not punish them for a response that would have been otherwise rewarded.
Individual trials immediately followed each other, as long as the chimpanzees were willing to continue participating.

As described in the main text, the chimpanzees also received at least 36 extra test trials (in blocks of twelve trials) with the forked tube. Each block of twelve trials followed the same pseudorandom order as for the initial twelve trials, with the exception of the special “opposite” trials (given to Holly and Cassie only). These trials involved the experimenter waiting for the chimpanzee to place one hand underneath one of the bottom openings of the forked tube, before turning/touching the wingnut screw and forcing the grape to come out of the uncovered opening.

**Mistrials.** Because the grapes were relatively small compared to the bouncy balls used with children, the wingnut screw and wooden platform were not 100% effective at forcing the grapes to come out of the intended bottom opening of the forked tube. Thus, there were a few mistrials in which a grape came out of the unintended opening. Mistrials that occurred during the regular pseudorandom order trials (no more than five times per subject) were corrected for on later trials, such that the grapes still came out of each bottom opening approximately 50% of the time. Only three mistrials occurred during the opposite trials, all while testing Cassie (trials 37, 44 and 47). They were not considered strongly problematic for interpreting the results, however, given that Cassie did not use the two-hand response on any of his 48 total trials, and given that we had already demonstrated it was possible to condition the two-hand response over many trials (with Samantha).

**Supplementary results.**

The response pattern of the most successful chimpanzee (Samantha) is summarised in the main text. Of the other subjects, Holly showed some evidence of the two-hand response in block 1 and the first block of opposite trials (block 4), so we continued testing her with blocks of pseudorandom and opposite trials. Even though she had used the two-hand response on four total trials (out of 94), however, she eventually refused to attempt the task when her one-hand response went continually unrewarded in the final block of opposite trials (block 8)—seemingly because she was frustrated with the apparent lack of a solution. Because Cassie showed no evidence of the two-hand response in either the regular pseudorandom trials or the first block of opposite trials, we decided to abandon testing him after trial block 4. His unambiguous failure of our task contrasts with his previous successes on many other cognitive tests (Collier-Baker, et al., 2006; Collier-Baker & Suddendorf, 2006; Hill, Collier-Baker, & Suddendorf, 2011; Nielsen, et al., 2005).

A more detailed summary of all three chimpanzees’ results is provided in Figure S3. This figure shows the same information as in Figure 4 of the main text, while also differentiating between trials in which the one-hand response was rewarded (i.e., when the chimpanzee guessed the correct bottom opening and caught the grape) and unrewarded. Across all regular pseudorandom order trials in which the one-hand response was used, Samantha covered the correct bottom opening.
20 out of 50 times (40%), Holly covered it 26 out of 57 times (45.6%), and Cassie covered it 17 out of 36 times (47.2%). None of these percentages significantly differed from chance level (50%), all $p > .20$, suggesting that the chimpanzees were not using any hypothetical external cue when deciding which hole to cover with their one-hand responses during these pseudorandom order trials.

Figure S3. Detailed summary of chimpanzees’ performance across all blocks of trials.

When considering all one-hand responses, Samantha used her right hand (to cover the left bottom opening from the experimenter’s perspective) on 36 trials (72%) and her left hand (to cover the right bottom opening from the experimenter’s perspective) on 14 trials (28%). Holly used her right hand on 56 trials (62.2%) and her left hand on 34 trials (37.8%). Cassie used his right hand only on all 48 trials. When considering consecutive one-hand responses only, Samantha swapped hands (right to left or vice versa) between trials 5 times out of 43 (11.6%) and Holly swapped hands 25 times out of 85 (29.4%).

See Figure S4 for a depiction of Samantha and Holly using the optimal two-hand response strategy. Samantha first used this strategy on trial 15, and used it on 34 total trials out of 84 (40.5%). Holly first used this strategy on trial 9, and used it on 4 total trials out of 96 (4.2%). Cassie did not use this strategy on any of his 48 trials.
Figure S4. Depiction of Samantha (left) and Holly (right) eventually using the two-hand strategy after many trials of using the one-hand strategy.
References


Chapter 7

Does Metarepresentation make Human Mental Time Travel Unique?
Preface

In the discussion section of the previous chapter, I suggested that spontaneously passing the forked tube task may typically rest on a capacity for forming metarepresentations. Specifically, the participant reflects on a single represented version of the future event, understands that this representation could be incorrect, and simultaneously prepares for the alternative version. The secondary, preliminary finding that three adult chimpanzees failed to spontaneously pass was therefore consistent with the failure of chimpanzees on other tasks requiring metarepresentational insight (e.g., Call & Tomasello, 1999), and with the suggestion that the capacity to form metarepresentations may be uniquely human (Suddendorf, 1999).

In the following chapter, I expand on these ideas and suggest that the capacity to form metarepresentations may be one fundamental element that makes human mental time travel unique. This chapter is written in the context of an ongoing debate in the comparative literature, between those who believe there to be qualitative differences between human and non-human mental time travel, and those who believe there to be quantitative differences only. Suddendorf and Corballis (1997; 2007) defended the uniqueness view of human mental time travel for more than a decade, although in the last year Corballis (2013a; 2013b; 2013c) has changed his mind. I discuss the neurological studies that caused this change in position, and behavioural studies of non-human mental time travel more generally, in the context of whether such studies can be taken as evidence for future-oriented metarepresentational insight.

This chapter is an adapted version of an article1 that has been accepted for publication. Therefore, many of the concepts and findings mentioned in the general introduction (Chapter 1) and review (Chapter 2) are briefly reiterated. I retain the journal outlet’s use of ‘boxes’ to discuss issues that are relevant but not central to the main argument of the article.

Abstract

Recent neurological evidence suggests that rats can mentally represent novel maze trajectories and then are more likely to follow these paths in the future. Consequently, it has been proposed that human and non-human mental time travel capacities may differ in degree rather than kind. As of yet, however, there is no evidence for the crucial and qualitatively distinct component of metarepresentation in any non-human animal, not even our closest great ape relatives. Metarepresentation allows humans to represent the relationship between current reality and mere representations of reality—including those of the future. Drawing on parallels with dreaming and mind-wandering, I outline the future-oriented benefits associated with uncontextualised (non-metarepresentational) representations of past and novel events, but propose that further, immense benefits flowed from the addition of metarepresentational insight. I critique previous behavioural paradigms used to assess mental time travel in animals and suggest how future-oriented metarepresentation might possibly be demonstrated nonverbally.
The ability to mentally travel in time to specific future episodes is one of the reasons humans have been able to dominate the environment and many other species on this planet (Suddendorf & Corballis, 1997). It allows us to actively shape the future to our own desire, seizing opportunities and avoiding potential harms (Suddendorf, 2006). The debate about whether (or to what extent) non-human animals can engage in mental time travel, however, remains unresolved and has recently taken an interesting turn. For more than a decade, mental time travel scholars Suddendorf and Corballis together defended the claim that there are qualitative differences between the human and non-human capacities (Suddendorf & Corballis, 1997, 2007, 2010; Suddendorf, Corballis, & Collier-Baker, 2009), whereas others have emphasised continuity across species (Clayton, Bussey, & Dickinson, 2003; Dere, Kart-Teke, Huston, & De Souza Silva, 2006; Osvath, 2010; Roberts, 2012; Zentall, 2005). Yet, in the last year, Corballis (2013a, 2013b, 2013c) has recanted his position of human uniqueness, on the basis of evidence suggesting that rodents can mentally represent novel maze trajectories before taking these paths in the future (Gupta, van der Meer, Touretzky, & Redish, 2010; Pastalkova, Itskov, Amarasingham, & Buzsáki, 2008; Pfeiffer & Foster, 2013). Suddendorf (2013a), on the other hand, rejects Corballis’ new stance, remaining committed to the proposal that there may be multiple limits to non-human mental time travel.

My intent here is not to provide a comprehensive account of all the potential similarities and differences between human and non-human mental time travel (instead see Cheke & Clayton, 2010; Clayton, et al., 2003; Feeney & Roberts, 2012; Roberts, 2002; Suddendorf & Corballis, 2007; Zentall, 2006). Rather, I wish to re-establish the crucial involvement of one qualitatively distinct and recently overlooked component of mental time travel—metarepresentation—that has not yet been demonstrated in animals. This capacity allows humans to represent the nature of the relationship between current reality and alternative representations of reality (Pylyshyn, 1978). Without metarepresentational insight, the future cannot be represented as the future (Suddendorf, 1999), which is a form of the temporal awareness central to conventional definitions of mental time travel (Tulving, 1985, 2005). Suddendorf and Corballis (1997, 2007) have previously argued for the decisive importance of metarepresentation to mental time travel, and there is no reason to reject the hypothesis of human uniqueness on the basis of current evidence. In the hope of refocusing the debate at this critical point, I first specify the role of metarepresentation in mental time travel before distilling and defending four key claims:

(i) In humans, mental representations of past and novel events are often dissociated from metarepresentational insight into the relationship between these events and current reality. Thus, even if animals are able to represent novel events, they may not have any ability to embed these representations within a specific future context.
There are numerous future-oriented adaptive benefits associated with uncontextualised mental representations of past and novel events, but there are further, immense benefits associated with metarepresentational insight into future events.

Many previous behavioural paradigms used to assess mental time travel in animals do not (and cannot) provide conclusive evidence for metarepresentational insight, and are more parsimoniously understood in terms of uncontextualised representations.

With careful controls, it is possible to provide evidence for metarepresentational insight in non-human mental time travel, if indeed the capacity exists.

**Metarepresentation and Mental Time Travel**

The term *metarepresentation* has been used in various frameworks (Perner, 2012), but Pylyshyn originally described it as the ability to “represent the representational relation itself” (p. 593). In the context of mental representations, this can be considered a recursive operation (Corballis, 2007, 2011; Martins, 2012) in which the mind represents the function of minds as to represent reality as it currently exists (via perception); or as it previously existed, could potentially exist, or could not exist (via imagination). Central to this capacity is the understanding that current reality exists independently of the mind, and that representations can be compared to this construct. Thus, an agent capable of forming metarepresentations can not only represent a belief, but also the notion of a belief and how it relates to the real world (Pylyshyn, 1978). This notion includes an explicit understanding that beliefs about current reality can be incorrect (Bennett, 1978; Dennett, 1978; Harman, 1978), and so human children are considered to possess a capacity for metarepresentation when they become able to pass an explicit false-belief task (Perner, 1991; Wimmer & Perner, 1983). More generally, metarepresentation allows humans to embed alternative representations of reality within a specific representational context—whether that context be another mind, the past, the future, or mere fiction—and relate these representations to our continuously updating model of current reality (Suddendorf, 1999, 2013b).

Perner (1991) greatly expanded on Pylyshyn’s ideas about metarepresentation, arguing for a qualitative difference between (i) a genuinely metarepresentational mind that represents the representational function of mental representations, and (ii) a mind that more simply distinguishes between representations tied to perception and purely imaginal representations. His case was that, since perception has been the most reliable source of information about current reality throughout evolutionary history, organisms must have evolved to give perceptual information precedence when interacting with the environment, without necessarily having any explicit theory-of-perception regarding why. Accordingly, organisms must have evolved to not treat alternative representations of reality as reality itself (because doing so would be incredibly dangerous), without necessarily having any metarepresentational notion about what a representation is. The difference between the
above cases (i) and (ii) is empirically demonstrated in the development of pretend play in human children.

Pretend play emerges during the second year of life (Leslie, 1987; Nielsen & Dissanayake, 2004), and even very young children do not typically confuse their pretend representations with current reality (e.g., when a banana is being represented as a telephone; Lillard, Pinkham, & Smith, 2011). Thus, young children are clearly able to simultaneously represent perceptual and imaginal models of the same situation, and they are able to interpret and use their imaginal models appropriately. Nevertheless, there is much evidence to suggest that, until around four or five years of age, children do not have a metarepresentational theory-of-pretence. Many younger children, for instance, will mistakenly attribute pretend play to mindless objects, such as a toy bus that has been made to look like a horse, or a toy car that has been made to move like a mouse (Lillard, Zeljo, Curenton, & Kaugars, 2000). Moreover, they will respond that a person hopping around like a kangaroo is pretending to be a kangaroo, even when told that the person has never seen a kangaroo before (Joseph, 1998; Lillard, 1993). To the mind of a young child then, pretence evidently exists in the world rather than as an intentional mental representation of the world (Lillard, 1996, 1998). And so, in accordance with Perner’s theory, it appears entirely possible for an agent to represent an alternative version of reality without any metarepresentational understanding of the relationship between that representation and current reality.

The point I wish to make here is that, just as the capacity for forming metarepresentations is required to represent the representational perspective of pretence, so it is also required to represent the future representational perspective. Without this ability, there can be no explicit understanding of how a representation of a plausible novel event can relate to current reality. Thus, metarepresentation interacts with the episodic system insofar as it enables episodic representations to be embedded within a specific future (or past) context, imbuing these representations with the temporal subjectivity that Tulving (2005) emphasises is necessary for true mental time travel. Yet, metarepresentation also interacts with the semantic system, insofar as it enables the encoding, storage and recall of a database of facts about the future context—for instance regarding the often uncertain nature of representations embedded within this context. And once these facts are crystallised, they can be maintained and called upon even in the event that the episodic system malfunctions (Kwan et al., 2012; Kwan, Craver, Green, Myerson, & Rosenbaum, 2013). Of course, a semantic database of facts about representations would be useless without a decision-based system to apply these facts appropriately, and so organisms capable of metarepresentation should possess mechanisms (potentially including episodic memory) that can set boundary conditions on semantic generalisations (Klein, Cosmides, Tooby, & Chance, 2002). The metarepresentational capacity may also interact with both declarative memory systems in other ways, for instance by
motivating agents to search for semantic information that will be useful only in specific future episodes (e.g., when business leaders invest millions of dollars in research and development; Suddendorf & Redshaw, 2013).

However, even when alternative representations of novel events are not embedded within a future context, this is not to say they are mistaken for the here-and-now (just as young children do not mistake pretence as such), because doing so would be disastrous from a survival perspective. Rather, these *uncontextualised representations* may sometimes function as lower-level ‘desired world states’ that can motivate present action (Boyer, 2008) or bias future action in an adaptive manner, without the agent having an explicit notion of the future representational perspective to which these desired world states belong. Uncontextualised representations may even enable basic forms of short-term planning, insofar as an agent is motivated to take a path from current reality to the desired world state. Yet, without metarepresentational insight, there can be no reflection on and judgement of these representations according to the particular features of future representations.

In the next section, I show that uncontextualised representations are common even in adult humans, and so neurological evidence suggesting that non-human animals are capable of representing novel events cannot be used in and of itself to infer that they can engage in true mental time travel.

### Uncontextualised Representations in Humans and Non-humans

The presence of a fully developed capacity for metarepresentation does not imply that adult humans always have metarepresentational insight into mental representations. Dreaming, for instance, clearly demonstrates the human brain’s ability to generate uncontextualised representations of novel scenarios, without any online understanding of the (discordant) relationship between these representations and current reality. Except in the special case of lucid dreaming (Voss, Holzmann, Tuin, & Hobson, 2009), we only gain insight into this relationship when we wake and our capacity for metarepresentation is applied. Curiously, a similar dissociation is seen in instances of involuntary mind-wandering to past and potential future episodes during wakefulness (Berntsen & Jacobsen, 2008; Smallwood, Nind, & O’Connor, 2009; Smallwood et al., 2011). People often become aware of the nature and temporal context of these representations only when their mind-wandering is interrupted and they reflect upon it after the fact (Jackson, Weinstein, & Balota, 2013; Sayette, Reichle, & Schooler, 2009; Smallwood, McSpadden, & Schooler, 2007). And yet, even when people mind-wander without any awareness of doing so, their behaviour is still driven by perceived reality, as demonstrated by the fact that they continue to perform appropriately (albeit less efficiently) on basic perceptual judgement tasks (Smallwood, et al., 2007). Human mind-wandering has been characterised as a process in which the mind intermittently wanders and then *catches itself* wandering, inadvertently halting the spontaneity of the process (Schooler et al., 2011). Thus, humans appear to possess mechanisms able to generate representations of past and
potential future scenarios without any necessary metarepresentational insight into their relationship with current reality. Such insight is an additional, rather than encapsulated ingredient of mental representation (see Figure 1).

Figure 1. Illustration of four instantiations of metarepresentation. A mind can represent an alternative version of reality (e.g., a dream, a past event, a novel event, or the content of another mind) without metarepresentational insight, which requires an additional, overarching representation of the relationship between that alternative version of reality and current reality. This represented relationship can be discordant (e.g., in lucid dreaming or fiction), post-occcurrent (e.g., in episodic memory), pre-occcurrent (e.g., in episodic foresight), or regarding the truth value of the alternative representation (e.g., in belief representation).

Both mammals and birds (but potentially not reptiles; Eiland, Lyamin, & Siegel, 2001) engage in rapid eye movement (REM) sleep (Hobson, 2009), which is closely associated with
dreaming in humans (Péters, Aerts, Delfiore, Degueldre, & Luxen, 1996; Stickgold, Hobson, Fosse, & Fosse, 2001). In rats, REM sleep is often coupled with the reactivation of hippocampal place cells corresponding to previously explored locations (Louie & Wilson, 2001), and behavioural evidence shows that pontine-lesioned cats appear to physically ‘act out’ their dreams (Hendricks, Morrison, & Mann, 1982). Furthermore, neuroimaging studies suggest that at least some mammalian brains have a human-like ‘default network’ (Barks, Parr, & Rilling; Lu et al., 2012; Mantini et al., 2011; Rilling et al., 2007), which has been implicated in mind-wandering during wakefulness (Mason et al., 2007). Thus, it appears that certain non-human animals may be able to generate mental representations of alternative versions of reality. And interestingly, as mentioned in the introduction, recent evidence suggests that rodents can represent novel movements through a spatial field (Gupta, et al., 2010; Pfeiffer & Foster, 2013). Indeed, during sleep and rest, novel representations may comprise up to 85% of the total running episodes generated by the rat brain (Dragoi & Tonegawa, 2014). As in human mind-wandering, rats’ alternative representations during wakefulness are apparently not confused with current reality, as they are able to continue running on a wheel in an appropriate fashion all the while imagining alternative movements through space (Pastalkova, et al., 2008).

Even conceding the phenomenological validity of these neurological findings, however, there remains no conclusive evidence for the capacity to form metarepresentations (as measured by false-belief understanding) in even our closest extant relatives, the great apes (Call & Tomasello, 1999; Krachun, Carpenter, Call, & Tomasello, 2009, 2010; Penn & Povinelli, 2007). This leaves open the possibility that, while some animals may have mechanisms able to generate uncontextualised representations based on elements from memory, they lack any insight into the specific relationship between these representations and current reality. And considering the numerous errors associated with memory (Schacter, 1999), it is not surprising that many of these representations would be novel, rather than accurate depictions of past events (evolution may even favour a somewhat imperfect memory that promotes the flexible recombination of memory elements; Schacter & Addis, 2007). Yet, as long as they are not embedded within a specific temporal context, such representations are best characterised as mental space travel rather than true mental time travel (see Box 1). As I reaffirm below, the capacity for metarepresentation is not only qualitatively distinct, but also exceptionally adaptive (Suddendorf, 1999).

**BOX 1: Mental space travel vs. mental time travel**

The capacity I describe as ‘mental space travel’ (used similarly by Tulving, 2005) is closely related to cognitive mapping (Hartley, Lever, Burgess, & O'Keefe, 2014). This concept was first introduced to explain the locomotive decisions of rats, including their ability to take novel short-cuts during maze runs (Tolman, 1948). Presumably, rats are able to do this because they have a
stored spatial representation of the maze and can mentally travel to different locations within this representation to implicitly deduce the shortest path between two points (O'Keefe & Nadel, 1978). The more recent work directly examining hippocampal place cells (Gupta, et al., 2010; Pastalkova, et al., 2008; Pfeiffer & Foster, 2013) only provides novel neurological support for this old cognitive theory. Undoubtedly, mental space travel even has a ‘temporal dimension’ to it, insofar as the spatial representation is not a static image, but rather changes over time in a coherent fashion. Evidence from hippocampal sharp-wave ripples suggests that rats mentally replay and pre-play specific movements in space, albeit at a rate around 10 times faster than their actual movement (Diba & Buzsáki, 2007). In this way, the mammalian hippocampus does indeed facilitate representations of ‘4D space-time’, as Corballis (2013c) suggests. The temporal dimension associated with the hippocampus (Itskov, Curto, Pastalkova, & Buzsáki, 2011), however, exists only within the mental representation itself. It does not allow the representation as a whole to be embedded in a specific temporal context relative to current reality.

There is no doubt that mental time travel co-opts the neural (hippocampal) and cognitive (representational) architecture provided by the more ancient capacity for mental space travel. Indeed, humans with hippocampal damage often struggle to represent past and potential future episodes (Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002), clearly demonstrating continuity with the basic representational capacities of other mammals. On top of mental space travel, however, humans have the metarepresentational ability to step outside their spatial representations, as it were, and see them for what they are (Suddendorf, 1999). In mental time travel, this involves placing these representations in time relative to a simultaneous representation of current reality. One recent study (Kwan, et al., 2013) suggests that, even though hippocampus-lesioned amnesics have trouble filling their representations with spatial content, they nevertheless still understand the relation between representations of the future and current reality (and they also have no trouble with false-belief tasks; Rabin, Braverman, Gilboa, Stuss, & Shayna Rosenbaum, 2012). This finding is consistent with Klein’s recently articulated view that mental time travel is greatly enhanced by, yet can still be dissociated from, the episodic system (Klein, 2013a, 2013b, 2013c). The capacity for metarepresentation is probably powered not by the hippocampus, but rather by the expanded human prefrontal cortex (Fleming & Dolan, 2012; Wheeler, Stuss, & Tulving, 1997).

**Evolutionary Perspective: Uncontextualised Representations vs. Metarepresentations**

One influential theory suggests that dreaming may have evolved to help us prepare for future threats (Revonsuo, 2000). By experiencing a novel situation in a dream, we are able to mentally ‘practice’ certain adaptive behaviours (Alexander, 1989). In this way dreaming would provide us with future-oriented benefits, although at the time of the dream and the applicable future situation we would usually remain unaware of these benefits. This hypothesis has support from various domains (Valli & Revonsuo, 2009), including from self-report studies showing that dreams often contain survival threats and attempted evasive or defensive action on the part of the dreamer (Zadra, Desjardins, & Marcotte, 2006). Indeed, a similar adaptive argument has been applied to uncontextualised representations of past and novel events during wakefulness. Mind-wandering or
environmental cueing to such episodes may bias humans and certain non-human animals to engage in adaptive behaviours when relevant future situations arise (Baird, Smallwood, & Schooler, 2011; Schooler, et al., 2011; Stawarczyk, Cassol, & D’Argembeau, 2013). Supporting this idea, rats that mentally represent spatial paths are more likely to take these paths in the future (Pastalkova, et al., 2008)—including when the represented path is novel (Pfeiffer & Foster, 2013)—potentially allowing them to discover new rewards.

Conceivably, the future-oriented benefits of uncontextualised representations could also be grounded in present behaviour. Consider the finding that human episodic memories often trigger limbic activity associated with the reactivation of emotional states from the actual past episode (Boyer, 2008; Damasio et al., 2000). Without any evidence to suggest otherwise, we can parsimoniously assume these emotional states to be coupled with the phenomenological reexperience of the episode itself, rather than any metarepresentational awareness of the episode’s relationship to current reality. If so, then it could be that certain animals, too, can reexperience (and pre-experience) emotional states when engaged in mind-wandering. Indeed, the chimpanzee default network seems to centre more on the ventromedial prefrontal cortex, which is associated with emotional processing, than the human network (Rilling, et al., 2007). Perhaps, emotional states associated with mind-wandering or environmental cuing could prompt animals into engaging in behaviours that would incidentally benefit their future selves. A hungry chimpanzee that comes across some stones, for example, might be cued into a representation of using these stones to crack nuts (a ‘desired world state’), and thus experience a specific desire for carrying stones to a place where nuts are available (see Boesch & Boesch, 1984). Even though the chimpanzee may be representing a removed spatial context, the adaptive behaviour could be triggered without any metarepresentational understanding of the specific temporal context of the represented episode (which may explain why they never refine stones for more efficient future use).

Without metarepresentational insight, however, the adaptive benefits of past and novel representations are limited. Specifically, an agent without this capacity might be restricted to uncontextualised representations of events that are consistent with evolutionarily recurring themes (e.g., potential survival threats; Nairne, Pandeirada, & Thompson, 2008; Nairne, van Arsdall, Pandeirada, & Blunt, 2012) or recombinations of personal past experiences (e.g., previously-taken and novel paths in a cognitively-mapped environment). Any long-term future benefits would be merely incidental rather than insightfully planned (but still common enough for the cognitive process to be naturally selected). An agent with a capacity for metarepresentation, on the other hand, is endowed with a general ability to embed their episodic representations into larger narratives (Suddendorf, 2013b). Such an agent can exert purposeful and powerful constructive control over a given future representation (within the constraints of the particular environmental
context in which it was triggered), and prepare with specific knowledge of how their behaviour may affect the future (Suddendorf, 1999). They can account for all (known) variables specific to a future context, such as the amount of time between a present behaviour and the future payoff, or the likelihoods of alternative versions of a future event occurring (Suddendorf & Corballis, 2007; Suddendorf & Redshaw, 2013). Agents with metarepresentational insight are not clairvoyants, but their future-oriented behaviours are likely to be far more targeted and adaptive than those of mere mind-wanderers.

**Empirical Concerns**

The empirical problem with the proposed qualitative cognitive difference between humans and non-humans, however, is that many of the future-oriented behavioural advantages it confers may be quantitative. Agents with a capacity for metarepresentation might be able to act to achieve desirable future outcomes, but so might agents without this component—albeit with less flexibility and without the same understanding. Indeed, there is no doubt that various instinctual, procedural, and semantic mechanisms can produce sophisticated future-oriented behaviour in many non-human species (Suddendorf & Corballis, 2007). And, more pertinently for the issue at hand, there remain non-metarepresentational explanations for evidence suggesting that certain animals can solve future problems using mental representations alone. Consider the most commonly cited behavioural evidence for great ape foresight. Studies show that individuals from these species can preferentially select a tool that will be useful in solving a future problem and gaining a reward (Mulcahy & Call, 2006), even when they haven’t seen the tool before (but have seen and used similar tools; Osvath & Osvath, 2008). These studies were designed only to answer the question of whether great apes can represent and act for novel episodes. Nevertheless, even if we grant them this capacity, the evidence does not (and cannot) imply a capacity for metarepresentation.

In humans at least, episodic memories are easily cued by relevant information (Tulving & Thomson, 1973), and recent evidence suggests that great apes too can be cued to representations of past events from up to three years earlier (Martin-Ordas, Berntsen, & Call, 2013). Furthermore, we know that great apes are capable of solving means-ends problems mentally, rather than through trial-and-error learning (Suddendorf & Whiten, 2001). Thus, when great apes are shown an array of novel objects, one of which can solve a previously experienced problem, they may be cued to their memory of the problem and become biased towards choosing the appropriate object. As we have seen earlier, however, representations of past and novel events do not necessarily occur with metarepresentational insight (Schooler, et al., 2011; Smallwood, et al., 2007). And so the apes could be cued towards selecting the right tool without any appreciation of the specific future context in which they can use it. Later on, when the problem becomes available again, they may be similarly cued to their past choice of the tool and thus bring it with them to gain the reward in the
present. Both of these behaviours are possible without any insight into the relationship between past, present, and future (see Figure 2).

**Figure 2.** An alternative, non-metarepresentational explanation for an experiment (Osvath & Osvath, 2008; experiment 4) that appears to show great apes acting for a specific future episode in which a novel hose is required to retrieve juice from a box. At time 1, the ape is aware of the general type of tool that is required to solve the problem (as they have already solved the problem in the previous experiments), but no specific solution is available. At time 2, the appearance of such a tool cues the ape to an uncontextualised representation of how to solve the problem, even though the problem is not currently available. This representation biases the ape towards choosing the appropriate object, albeit without any appreciation of the specific future context in which it can be used. The problem solution at time 3 is similarly based on an uncontextualised representation of the past choice of the tool, and a desire to solve the problem in the present.

Similar concerns arise when considering the case of Santino the chimpanzee, who has been observed to gather collections of stones, sometimes hiding them under piles of hay, before later hurling them at visitors to his zoo enclosure (Osvath, 2009; Osvath & Karvonen, 2012). Rather than necessarily requiring metarepresentational insight, such behaviour could have parallels with
the pretend play seen in human children less than four years of age. As described earlier, these young children are able to simultaneously represent current and pretend versions of reality without confusing one for the other, albeit with no understanding of how the representations specifically relate. Similarly, Santino’s stone-collecting behaviour could have been driven by an uncontextualised representation of zoo visitors appearing (which he had experienced many times before), without any understanding of the temporal context in which that representation would become actualised. And when the visitors did eventually appear, he simply took advantage of the stones he had left in a convenient location (children, too, leave their toys lying around). Although the behaviour clearly seems oriented to a specific future representational perspective, a careful analysis shows there is no need to ascribe any metarepresentational insight. Indeed, the authors themselves raise this possibility when they suggest that Santino’s behaviour could have been produced without any ‘theory-like reasoning’ about his own or others’ mental states (Osvath & Karvonen, 2012).

A Foresight Equivalent of the False-belief Task

The explicit false-belief task is the acid test of metarepresentation in the theory of mind domain because passing it requires the central understanding that mental representations are just representations and they can misrepresent current reality (Perner, 1991). Human children younger than four may be able to implicitly track and switch between their own and others’ mental representations, but, as in early pretend play, they may not represent the function of these representations as to represent the world from a certain perspective (Perner, Rendl, & Garnham, 2007)—and so they cannot pass the explicit false-belief task. Along these lines, any acid test of future-oriented metarepresentation must be able to differentiate between (i) an agent that can represent the function of future representations, and (ii) an agent that can more simply represent and act on lower-level desired world states, with no explicit understanding of the future representational perspective to which these desired world states belong. And, as for the theory of mind domain, perhaps the most empirically tractable functional element of future representations is that they often misrepresent the future. Indeed, any agent that explicitly represented the future representational perspective might be expected to learn about the uncertain nature of future representations rather quickly. Thus, any non-human animal that demonstrated compelling behavioural evidence of understanding future misrepresentation could be said to possess a future-oriented metarepresentational capacity.

Well established in the literature, the Bischof-Köhler hypothesis proposes that non-human animals cannot act with future desires in mind when they conflict with current desires (Suddendorf & Corballis, 1997). Such action may rely on a capacity for metarepresentation because it requires an agent to understand that the current self tends to misrepresent certain aspects of the future self
and so behaviour should be adjusted accordingly. As we have seen earlier, however, episodic memories can reactivate emotions associated with the memory (Boyer, 2008; Damasio, et al., 2000), and so this may also occur when animals mind-wander or are cued to uncontextualised representations of past or novel scenarios. In this way, an animal might be able to act with a future emotion in mind, simply because they are currently experiencing that emotion to a certain extent (e.g., in the case of Santino). This low-level explanation could also apply to studies of specific satiety in corvids (see Box 2). Thus, emotion-based tests of the Bischof-Köhler hypothesis may be inadequate if one is hoping to measure metarepresentational insight.

**BOX 2: ‘Planning’ by corvids: Metarepresentation or emotional cueing?**

An excellent and long-standing program of research from Clayton and colleagues appears to demonstrate that various birds from the *Corvidae* family (corvids) can cache food with specific future desires in mind (Correia, Dickinson, & Clayton, 2007; Raby, Alexis, Dickinson, & Clayton, 2007). Here I will focus on just one of their studies, which a prominent sceptic recently called “the most convincing evidence of planning in another species” (Shettleworth, 2012, p.2795).

Cheke and Clayton (2012) tested Eurasian jays (*Garrulus glandarius*). The authors based their paradigm on the concept of ‘specific satiety’, whereby an animal exhibits a reduced preference for a specific food (in contrast to other foods) after becoming sated on that food. All experimental factors were counterbalanced across four subjects, but for ease of communication I will describe the procedure experienced by a single bird. In three sequential stages over two days, this bird was:

- (i) allowed to cache food A and food B in both tray 1 and tray 2,
- (ii) pre-fed food A only, before being allowed to retrieve food from tray 1 only,
- (iii) pre-fed food B only, before being allowed to retrieve food from tray 2 only.

This three-stage process was repeated over three trials. In the first (baseline) trial, the bird was not pre-fed food A or food B before the first (caching) stage, and did not exhibit any preferences for caching specific foods in specific trays. In the second and third trials, however, the bird was pre-fed food A before the first stage. In these second and third trials, the bird cached a higher proportion of food A in tray 2 than tray 1. Therefore, the bird was caching more of food A in the location that would be available when it would prefer this food in the future.

To their credit, the authors do not attribute a metarepresentational capacity to the birds without qualification. Rather, they offer an alternative interpretation of their results that is consistent with the Bischof-Köhler hypothesis and the more general argument presented herein. They imply that, during the baseline trial, the bird could have associated the availability of tray 1 with an emotional preference for food B (stage ii), and the availability of tray 2 with an emotional preference for food A (stage iii). And, in the subsequent trials, these emotional preferences could have been reactivated upon the appearance of the trays during the first stage—thus over-riding the bird’s distaste for food A based on the pre-feeding. The reactivated emotional preferences would in turn motivate caching behaviour that was incidentally consistent with the bird’s future preferences, without the bird having any explicit understanding of the specific relationship between their caching behaviour and the future retrieval event.
On the other hand, it remains unclear to what extent motivational drives such as generalised hunger (in contrast to appetite for specific foods), thirst, and temperature sensitivity can be reactivated by episodic memory or mind-wandering. In primates at least, such ‘interoceptive’ states arise directly from the peripheral nervous system (Craig, 2002, 2003), and so they may be less susceptible to reactivation and cognitive appraisal than emotions are. If so, then these drives would make ideal candidates for testing the Bischof-Köhler hypothesis in this particular animal order. Studies that have claimed to provide evidence of great apes acting for future hunger levels (Osvath & Osvath, 2008) have failed to include a conflict with present hunger levels, and so it remains unclear which one the animal is acting upon (Suddendorf, et al., 2009). A more sound experiment would require the animal to act to reduce a strong future drive even when they are completely sated (Suddendorf, 1994). Illustrating the trouble that non-human primates may have with this behaviour, D’Amato observed that, day after day, cebus monkeys would throw food out of a cage when sated, only to later find themselves hungry and with nothing to eat (Roberts, 2002).

Nevertheless, although interoceptive state-based tests of the Bischof-Köhler hypothesis can potentially provide existence proof of future-oriented metarepresentation, in some ways they may be setting the bar too high. Among humans, even 7-year-old children (and at times, adults; Nisbett & Kanouse, 1969) have great difficulty passing such tests (Atance & Meltzoff, 2006; Mahy, Grass, Wagner, & Kliegel, 2014), despite the fact they pass metarepresentational tasks in the theory of mind domain around age four (Wellman, Cross, & Watson, 2001). And so it may be fruitful to search for other means of testing the capacity based on an understanding that future events can be misrepresented, rather than the future self. One possibility could be to test whether animals can prepare for multiple, mutually exclusive versions of a single undetermined future event. Such a test may provide a first-person, future-oriented version of the false-belief task, because it would require the animal to recognise that a represented version of the future could be incorrect and also prepare for alternative versions. In other words, it would require the animal to represent the uncertain nature of the relationship between current reality and the future (as it is represented by the mind). Importantly, the criteria for passing should involve preparing for multiple potential outcomes of the single event simultaneously, thus ensuring that the behaviour is not simply based on sequential uncontextualised representations of the outcomes. Current evidence suggests that children become capable of such behaviour around the fifth year (Beck, Robinson, Carroll, & Apperly, 2006; Robinson, Rowley, Beck, Carroll, & Apperly, 2006).

Conclusion

Non-human animals are capable of many impressive future-oriented behaviours, and they may even be able to mentally represent basic novel events. As of yet, however, they have shown no evidence of metarepresentational insight into the relationship between future events and current
reality. Without this capacity, they would be extremely limited in their ability to intelligently prepare for specific future episodes. Future research may reveal otherwise, but for the moment the hypothesis that there are qualitatively distinct aspects of human mental time travel remains tenable.
References


Barks, S. K., Parr, L. A., & Rilling, J. K. The default mode network in chimpanzees (Pan troglodytes) is similar to that of humans. Cerebral Cortex, (in press).


Cheke, L. G., & Clayton, N. S. (2012). Eurasian jays (Garrulus glandarius) overcome their current desires to anticipate two distinct future needs and plan for them appropriately. Biology Letters, 8(2), 171-175.


Kwan, D., Craver, C. F., Green, L., Myerson, J., & Rosenbaum, R. S. (2013). Dissociations in future thinking following hippocampal damage: evidence from discounting and time


Chapter 8

General Discussion
Episodic foresight has been defined as “the capacity to imagine future scenarios and use such imagination to guide current action” (Suddendorf & Moore, 2011, p. 296). It can be considered the future-directed counterpart of episodic memory, and indeed there are many links between the abilities to imagine past and future events (Schacter et al., 2012; Suddendorf, 2010). In Chapter 2’s review, however, I demonstrated that episodic foresight is more than just the ability to project past events into the future. Rather, it is a multifaceted process involving several sophisticated and interconnected cognitive components that can be considered analogues of the roles involved in a theatre production—the stage, playwright, set, actors, director, executive producer, and broadcaster (Suddendorf & Corballis, 2007). These components develop along varying trajectories, with important milestones in each of them achieved between ages three and five. The following four chapters involved empirical studies examining the development of several novel future-oriented behaviours in children around these ages. These behaviours included solving deferred future problems (Chapter 3), seeking information for specific future episodes (Chapter 4), remembering to carry out an intended future action in the presence and absence of external cues (Chapter 5), and preparing for alternative versions of the future (Chapter 6). Overall, the findings further substantiate the claim that episodic foresight shows crucial developments throughout the preschool years. In Chapter 7, I built upon a discussion point arising from a preliminary study with chimpanzees in Chapter 6, and suggested that the capacity to form metarepresentations may make human episodic foresight unique.

In this general discussion, I will first summarise the findings of each empirical chapter before elaborating on them in greater detail and outlining potential avenues for future research. I will then provide an age-based analysis of the findings, bringing together evidence from across the studies to consider the development of episodic foresight and future-oriented behaviour between ages two and five. Afterwards, I will revisit the theatre metaphor and discuss whether any additions or alterations should be made to the components. I will conclude with a short summary of the overall contribution of my thesis to the theoretical, developmental, and comparative episodic foresight literatures.

Summary and Extended Discussion of Empirical Findings

In the following sections I summarise the findings of the empirical chapters (3-6) while also embedding them within the broader developmental literature and discussing them in the context of the theatre metaphor. For each study I outline the novel methodological and theoretical contributions made, and suggest how future research might proceed.

Chapter 3: Preparing for Deferred Future Episodes

Previous studies had shown that preschoolers can select objects to solve future problems that are merely hypothetical (Atance & Meltzoff, 2005) or occur almost immediately after the object is
selected (Scarf, Gross, Colombo, & Hayne, 2013; Suddendorf, Nielsen, & von Gehlen, 2011). Chapter 3’s study was the first to examine children’s ability to recall a problem from the past and act in the present to solve that problem in a deferred future episode. I used a modified version of the two-room paradigm developed by Suddendorf and colleagues (2011). In the crucial test condition, 4-year-old children were taken to a first room and exposed to a problem, but there was no solution available. They were then taken to a second room and distracted for 15 minutes, before being told that (i) they would be going back to the first room when a familiar 5-minute sand-timer had completed a cycle, and (ii) they would be taking a bucket when they went. After the children confirmed they understood these facts, the experimenter revealed a selection of six items (one of which could solve the problem in the first room) and told the children that they could place one of the items into the bucket. The children placed the item that could solve the problem significantly more often than chance would predict, suggesting that many 4-year-old children can act in the present to solve deferred future problems.

Chapter 3’s innovative use of a sand-timer to examine children’s episodic foresight has the potential to be adopted in many future studies (see, e.g., Chapters 4 and 5). The 4-year-olds solved the deferred future problem marked by the timer at a similar rate to the 4-year-olds from Suddendorf and colleagues’ (2011) original study, who only had to act for the very next future episode (‘now’). Such a pattern of results may suggest that, as long as children can correctly recall a problem from the past, they can use the same cognitive mechanism to solve that problem for an episode in the immediate future and for an episode 5 minutes into the future. This raises the possibility that children (and adults) can also use the same mechanism to solve even more distant future problems, again as long as they can recall the relevant past episode. For example, as long as children can recall the problems that they typically face throughout a day at preschool, then they may be able to pack their bags with items that solve these deferred future problems (e.g., a hat to protect from the sun) using the same cognitive mechanism as if the problems were in the immediate future.

The central importance of episodic memory in the ability to solve two-room problems is also supported by a recent study from Atance and Sommerville (2014). They found that variance in 3-5 year-old children’s memory for the relevant problem could explain all age-based differences in their ability to select the appropriate item that could solve the problem in the future. These findings and Chapter 3’s results are both consistent with the links between episodic memory and episodic foresight seen across domains (Suddendorf, 2010), and with the proposal that episodic memory may have evolved as a crucial design feature of the episodic foresight system (Klein, 2013; Suddendorf & Busby, 2003, 2005).
In the context of the theatre metaphor, Chapter 3’s task examined whether there are extra demands placed on the *set* component of episodic foresight when the relevant future episode is moved beyond the very next event. The results, when considered in tandem with those of Suddendorf and colleagues (2011), suggest that there may not be any such demands. Nevertheless, in some situations where we must act for a deferred future episode, the goal of that episode directly conflicts with the goal that we have in the immediate future. In these cases there may be extra demands on the *executive producer* component, because we must be able to inhibit the desire to achieve the more immediate goal. Several previous studies have tested children’s capacity to do this, in the context of delaying gratification (e.g., Mischel, Shoda, & Rodriguez, 1989; Thompson, Barresi, & Moore, 1997) or acting for future rather than present food preferences (Atance & Meltzoff, 2006; Mahy, Grass, Wagner, & Kliegel, 2014). Another way to test this capacity, however, could be to examine children’s performance on an item-choice paradigm in which the item that would solve an immediate (but inaccessible) future problem is not the same one that would solve a more distant (but accessible) future problem. Solving the accessible problem would still require the children to act for a deferred future goal that is incongruent with an immediate goal, without also requiring them to inhibit strong physiological drives.

**Chapter 4: Future-oriented Information Seeking**

Previous studies have shown that young children have an innate preference for certain novel information (S. Friedman, 1972; Slater, Morison, & Rose, 1984) and are able to seek specific information to achieve a present goal (Call & Carpenter, 2001). Chapter 4’s studies were the first to directly examine children’s ability to seek and encode information that would only be useful in a future episode. In Study 1, I again adapted the two-room paradigm previously used in Chapter 3, and gave 4- and 5-year-old children the opportunity to seek information that would solve a future problem in another room. When low-level associative explanations were controlled for (in Experiment 1B), 5-year-olds but not 4-year-olds showed evidence of being able to selectively search for information that would be useful in the future. Nevertheless, because the two-room paradigm also places considerable demands on episodic memory (see above), it was difficult to conclude why the 4-year-olds failed. In Study 2, I relaxed memory demands and gave 4- and 5-year-olds the opportunity to study information for a future test. Again, 5-year-olds but not 4-year-olds provided evidence that they could narrow their search to information that would be beneficial in the future, with analyses revealing that this explained the difference in test performance between the groups.

The results of Chapter 4 have important practical implications, considering that future-oriented information seeking is particularly important during the schooling years when children begin to engage in activities like studying and homework. Although 5-year-old preschoolers as a
group did perform above chance on two structurally distinct tasks, the fact that they did not perform even close to ceiling levels suggests there is much room for improvement. Thus, future studies may wish to examine whether the youngest schoolchildren reach ceiling level. If not, then it would be ideal to test whether children can be trained to enhance their performance. One potential target of such training could be executive functions, given that selective future-oriented information seeking may require children to inhibit their natural preference for other novel information (S. Friedman, 1972; Slater, et al., 1984). Some research suggests that interventions can facilitate young children’s executive function development, and this effect appears particularly strong for children with poor executive functions to begin with (Diamond & Lee, 2011; Zelazo & Carlson, 2012).

Besides loading heavily on the executive producer component of episodic foresight, future-directed information seeking tasks may also place strong demands on the actor component. Specifically, to perform optimally on such tasks, children must recognise that their future self will be relying on memory for information gained in the relative past (which is now the present). In this way, they may understand that their future performance will benefit from active encoding and rehearsal of that information in the present. In Chapter 4, I introduced the term ‘doubly embedded mental time travel’ to describe this capacity (see Figure 1), and suggested that differences in the propensity to use it may have been responsible for the various differences in task performance between the 4- and 5-year-olds.
Figure 1. Representation of the difference between singly and doubly embedded mental time travel, which may explain why future-oriented information seeking could be particularly difficult for young children. To perform optimally on a future-directed information seeking task, you must not only consider your future self, but also how that future self will use knowledge gained in the relative past (now the present) to solve the problem.

The concept of doubly embedded mental time travel could provide a new framework bringing together evidence for the development of various cognitive and emotional capacities in children. In Chapter 4, I described how this concept might also be important for prospective memory, in particular when children internally rehearse prospective intentions to enhance their future memory. Consistent with the results of Chapter 4, such internal rehearsal appears to emerge around five years of age (Mahy & Moses, 2011; also see Chapter 5). Interestingly, doubly embedded mental time travel in the opposite direction might be important in the experience of regret, in which one reflects on a past decision that could have resulted in a more appealing relative future (present). Again consistent with Chapter 4’s results, the earliest evidence for regret may appear in 5-year-olds (Weisberg & Beck, 2010, 2012). Future research may want to check for correlations between future-directed information seeking and these other versions of doubly
embedded mental time travel, as well as other types of doubly embedded cognition more generally (e.g., second-order belief reasoning, which may also emerge around five years; Miller, 2009; Sullivan, Zaitchik, & Tager-Flusberg, 1994). Incidentally, children begin to show evidence for triply embedded mental time travel (in the form of predicting future regret) only around age nine (Guttentag & Ferrell, 2008). In the theory of mind domain, fifth-order mental state relations may typically be the highest form that humans can hold in working memory at any given time (Kinderman, Dunbar, & Bentall, 1998; Stiller & Dunbar, 2007), and it would be interesting to examine whether similar constraints exist for mental time travel. A fifth-order example of mental time travel might involve you imagining a future in which you will reflect on how you could have anticipated regret in the past (as a criminal faced with a long prison sentence may do).

Future research may also wish to investigate the relationship between future-oriented information seeking and the capacity to deliberately practice physical skills in order to improve future performance. As described in Chapter 2, future-directed practice can explain much about why humans show such large differences in skills and competencies at the individual level, and one could say that future-oriented information seeking is a form of ‘deliberate practice for the mind’. There is very scarce literature, however, regarding young children’s physical practice, and I could find no published studies on their ability to selectively practice certain skills with future performance in mind. The paradigms described in Chapter 4 could easily be adapted to examine this capacity. Children could, for instance, be given a choice of a number of physical tasks to practice—including one that that will be tested in the future and several that will not. Their subsequent behaviour could then be examined to see whether they devoted more time to practicing the future-relevant skill than would be expected by chance.

**Chapter 5: Time-based Prospective Memory**

Previous studies of children’s time-based prospective memory have included cues (such as a visible clock) that allowed the children to off-load the need to internally rehearse and implement the future intention to an external source (e.g., Aberle & Kliegel, 2010; Ceci & Bronfenbrenner, 1985; Mackinlay, Kliegel, & Mäntylä, 2009; Voigt, Aberle, Schönfeld, & Kliegel, 2011). Chapter 5’s study was the first to examine preschool children’s ability to remember to perform an action at a certain time in the future, in both the presence and absence of reminders. I administered 3-, 4-, and 5-year-olds a novel paradigm in which their basic task was to remember to ring a bell at the end of a familiar 1-minute sand-timer’s cycle. The experiment involved a 2 x 2 within-subjects design. In half of the conditions the timer was visible, and in the other half the timer was covered such that the children had no external cue for when to ring the bell. In half of the conditions the timer appeared as a single task, and in the other half (the prospective memory conditions) the timer was moved around a picture board, with children having to say the names of the pictures as they were marked.
by the timer. The main results showed that children were less likely to remember to ring the bell when the timer was hidden and/or embedded within the dual picture-naming task, with performance across all conditions improving with age.

The children performed relatively well in the prospective memory condition in which the timer was visible and embedded within the dual task. More than half of the 4-year-olds and nearly all of the 5-year-olds remembered to ring the bell in this condition, and most of these children did so at the appropriate time. This suggests that the capacity to retain a future intention and carry it out when cued develops during the preschool years, consistent with much previous research in the developmental prospective memory literature (e.g., Aberle & Kliegel, 2010; Guajardo & Best, 2000; Kliegel & Jäger, 2007; Kvavilashvili, Messer, & Ebdon, 2001).

The children experienced much more difficulty, however, in the novel condition where the timer was hidden and embedded within the dual task. In this condition, none of the 3-year-olds, very few of the 4-year-olds, and just under half of the 5-year-olds remembered to ring the bell at any time during the task. Without the sand constantly falling and reminding them of the requirement to ring the bell, the children had to rely more heavily on their own, internal reminders to do so. Thus, the results are consistent with previous literature suggesting that the capacity to internally rehearse prospective intentions begins to emerge only around five years of age (Mahy & Moses, 2011). Such internal rehearsal may place a particularly high demand on executive resources, as supported by the finding that executive function measures independently predicted performance and accuracy in the hidden conditions of the timer task but not the visible conditions. And so, in the context of the theatre metaphor, it could be said that performance in the hidden conditions relied more heavily on the executive producer component of episodic foresight. It could also be said that performance relied more heavily on doubly embedded mental time travel (see above), given that internal rehearsal of prospective intentions may fundamentally rest on knowledge about how future memory can be improved.

Chapter 5’s results suggest that preschoolers will struggle to remember to perform specific tasks in the future unless there is an external reminder to do so (such as a parental request). The capacity to act without reminders will become increasingly important as children become older, and so future studies may wish to investigate development beyond the preschool years. As suggested in Chapter 2, future studies may also wish to investigate when and how children become able to generate their own prospective intentions. In the Chapter 5 task (and all other published prospective memory tasks given to children and other populations), the participants were given the intention by the experimenter who explained the requirement to ring the bell. The ability to self-generate future intentions could be tested by giving children the opportunity to spontaneously mark a piece of
information that will be relevant in the future, which may demonstrate an understanding of how this
mark will assist their future memory.

The results of Chapter 5 have important implications for the broader prospective memory
literature, given that nearly all previous measures of time-based prospective memory with all
populations have included visible reminders about when to perform the crucial action (for reviews,
see Kvavilashvili, Kyle, & Messer, 2008; McDaniel & Einstein, 2007). Our results show that when
such cues are removed and participants are forced to rely on their own, internal reminders,
performance is greatly reduced. The paradigm was designed to be used with very young children,
as Chapter 3’s results had shown that preschoolers can work with sand-timers as concrete
instantiations of time. Nevertheless, the task can easily be adapted for use with other populations
that may experience difficulties with prospective memory (see, e.g., Altgassen, Williams, Bölte, &
Kliegel, 2009; Costa, Peppe, Caltagirone, & Carlesimo, 2008; Henry, MacLeod, Phillips, &
Crawford, 2004; Henry, Rendell, Kliegel, & Altgassen, 2007; Kliegel, Ropeter, & Mackinlay, 2006;
Rendell, Mazur, & Henry, 2009). In collaboration with colleagues (Thomas Suddendorf and Julie
Henry), I have developed a computerised version of the paradigm that we are currently
administering to a sample of older adults (using arithmetic problems for the dual-task instead of
picture-naming). This version allows more precision in measurements of performance and
accuracy, greater control of the length of the timer’s cycle and its movement around the board, and
full control over the size of the board and the arithmetic problems to be answered (see Figure 2).
We hope to test several other populations in the future.
Figure 2. A modified, computerised version of Chapter 5’s prospective memory paradigm that can be administered to older children and adults. The familiar timer moves around the board in a pseudorandom order, while the participant answers the corresponding arithmetic problems and must remember to press the spacebar when the timer’s cycle is completed. In one condition the timer is visible, in one condition the timer is covered, and in one condition the participants can press a button to reveal the timer for one second at a time.

Chapter 6: Preparing for Alternative Futures

Previous studies of children’s ability to prepare for alternative versions of a single future event have included complex intermediate steps between the preparatory behaviour and the future outcome, while also relying heavily on language and unnatural behavioural responses (Beck, Robinson, Carroll, & Apperly, 2006; Robinson, Rowley, Beck, Carroll, & Apperly, 2006). Chapter 6’s study introduced the first minimalist behavioural paradigm assessing this capacity. I administered 2-4 year-old children a novel task in which they were given the opportunity to catch a ball dropped into a forked tube with one opening at the top but two openings at the bottom. Very few 2-year-old children, many 3-year-olds, and most 4-year-olds spontaneously covered both bottom openings of the tube when preparing to catch the ball on the first trial, suggesting they understood the particular contingencies of the task. Many other children succeeded on later trials, but the specific pattern of results suggested this was due to simple trial-and-error learning. I also administered a preliminary test of the same paradigm to three adult chimpanzees, with none of them...
spontaneously covering both bottom openings on the first trial but one learning to reliably do so after many trials.

The results of this study show that many 3-year-olds and most 4-year-olds understand that the (immediate) future is uncertain and are consequently able to ‘hedge their bets’ and prepare for multiple alternative outcomes. When children begin to understand the uncertain nature of representations embedded within the future context, they can begin to take advantage of these representations in novel ways. To use a helpful spatial metaphor, children may no longer be constrained to envisioning and preparing for the future as if it were a single vector extending from the present—instead they may represent and prepare for the future as if it were a branching tree with multiple possibilities extending from each junction. In the context of the theatre metaphor, this role is performed by the director analogue, and so the forked tube task could be considered a critical test of this component.

As suggested in Chapter 6’s discussion section, one component of episodic foresight that may be fundamentally important in spontaneously passing the forked tube task is the capacity to form metarepresentations (Perner, 1991; Pylyshyn, 1978; Suddendorf, 1999). This ability allows humans to reflect on a representation of a single version of a future event, understand that this representation could be incorrect, and simultaneously prepare for an alternative version. The developmental pattern observed on the forked tube task was similar to that seen on explicit false-belief tasks (Rubio-Fernández & Geurts, 2013; Wellman, Cross, & Watson, 2001), which require children to recognise and act on the incorrect mental representation of another agent (Wimmer & Perner, 1983) or their own incorrect representation from the very recent past (Gopnik & Astington, 1988). This parallel raises the possibility that passing both tasks typically requires a capacity to form metarepresentations, although future research could check for correlations more directly.

Future studies could also modify the forked tube task in many ways to more conclusively narrow down the cognitive components that are typically required to spontaneously pass. One simple modification could be to make the tube transparent, such that it becomes obvious which bottom opening the ball will fall from on any given trial. In this case the future outcome is not uncertain, and so one might expect children with insight into the contingencies of the task to use the one-hand response more often than they would with the original opaque tube. Such a result would diminish the likelihood that children typically pass the original task with a low-level, non-metarepresentational strategy such as “cover all holes where balls have previously fallen from”.

Two other potential modifications (using regular opaque tubes) are depicted next to the original apparatus in Figure 3. In the first proposed apparatus, there is again a single future event that children must prepare for, but this time there are more than two possible outcomes, meaning that the children cannot cover all holes when preparing to catch the ball. In the second proposed
apparatus, however, there are two future events (two balls) that children must prepare for at the same time, but only one possible outcome given that each ball can only come out of one hole. If my interpretation of Chapter 6’s data is correct—that young children do not spontaneously use the two-hand response on the original task because they struggle to understand alternative outcomes—then the same young children should have difficulty spontaneously using the two-hand response on the first proposed apparatus but readily use this response on the second proposed apparatus.

Figure 3. Representation of the original apparatus used in Chapter 6 alongside two proposed apparatuses. Proposed Apparatus 1 is conceptually similar to the original apparatus because there are multiple possible outcomes of a single future event; whereas Proposed Apparatus 2 is conceptually distinct because there is only one possible outcome for two future events.

Once the components required to pass the forked tube task are narrowed down, it would be interesting to examine the performance of populations other than typically developing children. Autistic children, for example, are known to struggle with false-belief tasks (Baron-Cohen, Leslie, & Frith, 1985), with some theories (Perner & Leekam, 2008) and data (Bowler, Briskman, Gurvidi, & Fornells-Ambrojo, 2005) suggesting they have a more general deficit in the capacity for forming metarepresentations. If they do have such a deficit, and if spontaneously passing the forked tube
task does typically rely on metarepresentational insight, then one might expect children with autism to use the two-hand response on the first trial at a lower rate than IQ-matched control children.

The forked tube task can also be easily administered to non-human primates, as the preliminary test with three chimpanzees demonstrated. These subjects showed no evidence of spontaneously using the two-hand response, although because the sample was small I recommended further testing with other chimpanzee individuals and other primates more generally (such testing could also incorporate the proposed task modifications discussed above). Nevertheless, as suggested in Chapter 6, the preliminary results do raise the intriguing possibility that humans’ closest living relatives cannot envision or prepare for alternative versions of even immediate future events. If spontaneously passing the forked tube task does typically rely on a capacity for metarepresentational insight, then a general inability of chimpanzees to pass in this manner would be consistent with their repeated failure on false-belief tasks (Call & Tomasello, 1999; Krachun, Call, & Tomasello, 2010; Krachun, Carpenter, Call, & Tomasello, 2009). It would also be consistent with the proposal that metarepresentations may be uniquely human (Suddendorf, 1999), and with the more specific idea proposed in Chapter 7 that the capacity to form metarepresentations is one fundamental attribute that makes human mental time travel unique.

The original forked tube task and proposed modifications each involve an immediate future event in which the behavioural preparation and future outcome occur in the same context. As suggested in Chapter 6, such minimalist tasks have the advantage of not conflating the central capacity of interest—preparing for alternative future event outcomes—with other capacities like imagining an appropriate spatial and temporal context for these alternative outcomes. Nevertheless, it remains possible that children find it more difficult to reason about alternative futures when the problem is not directly in front of them, because doing so places extra demands on the stage, playwright, and set analogues of the episodic foresight theatre metaphor. Future studies should investigate this possibility, although it is difficult to imagine how such studies could retain the same high level of experimental control and reduced language demands that make the forked tube task so appealing.

**Age-based Summary and Analysis of the Findings**

The four empirical chapters included participants aged between two and five years old. Although none of the studies tested children from all of these age groups, each study (with the exception of the experiment described in Chapter 3) included a group that performed at a baseline level on the critical task, and so it is fairly safe to assume that younger children would also perform at this level. One can therefore consider the aggregation of results in the context of what they say about the episodic foresight capacities of children as they move through the preschool years, with reference to the literature reviewed in Chapter 2.
Two-year-olds

Two-year-old children were tested in Chapter 6’s forked tube study. Very few of them spontaneously prepared for alternative future outcomes when given the opportunity, although many more demonstrated that the physical coordination required to pass the task was within their capacity on the later trials. This lack of spontaneous success may suggest that 2-year-olds typically fail to represent even immediate future events as being uncertain. If so, then it could be that they lack a metarepresentational notion of future representations. Specifically, they may lack insight into the fact that they represent future events from a certain perspective, and this perspective may or may not turn out to be correct in its representational content. Two-year-olds are certainly proficient at imagining alternative scenarios of the world as in pretend play (Lillard, Pinkham, & Smith, 2011; Nielsen & Dissanayake, 2004), but without a notion of the future representational perspective they cannot embed such alternative scenarios within a particular future context (see Chapter 7). In this case, 2-year-olds would be limited in their capacity to demonstrate flexible, intelligent future-oriented behaviour.

This is not to say, however, that 2-year-olds would be indistinguishable from younger children in their future-oriented cognition and behaviour. There is much evidence to suggest that, throughout the second year, children become able to bring past event sequences to mind (Bauer, 1996; Bauer & Leventon, 2013) and they also become able to generalise these past event sequences to novel contexts (Bauer & Dow, 1994). Furthermore, many 2-year-olds appear able to represent and execute novel action sequences in order to achieve an immediate goal (Bauer, Schwade, Wewerka, & Delaney, 1999). These capacities may have some parallels with the uncontextualised representations I discussed at length in Chapter 7, which potentially provide non-human animals and young children with future-oriented benefits even if they lack a metarepresentational notion of what future (or past) representations are. Specifically, 2-year-olds’ uncontextualised representations of immediate goal states could function to motivate short-term means-ends reasoning and action (see Boyer, 2008; Hesslow, 2002; McCormack & Atance, 2011; Suddendorf & Whiten, 2001). Uncontextualised representations could also be involved in the basic talk about past and future events shown by 2-year-olds in conversations with their parents (Fivush, 2011; Fivush, Gray, & Fromhoff, 1987; Hudson, 2002, 2006). In theory, there is nothing to prevent children from discussing the content of their representations when cued, even if they struggle to embed these representations within a particular temporal context (see Perner, 1991).

Three-year-olds

Three-year-old children were tested in Chapter 5 and 6’s studies. Unlike the 2-year-olds, many 3-year-olds were able to spontaneously prepare for alternative future outcomes in Chapter 6’s forked tube study, suggesting they represented the uncertain nature of the immediate future event.
This might indicate that children typically begin to form a metarepresentational notion of future representations late during the third year of life. Three-year-olds struggled, however, on Chapter 5’s prospective memory tasks, with few of them remembering to carry out the future intention when they had an external cue and none of them remembering to do so without the cue. Three-year-olds also struggled in the original study that Chapter 3’s two-room task was based on (Suddendorf, et al., 2011), suggesting they would experience similar difficulties with recalling a problem from the past and acting to solve that problem for a deferred future episode. To summarise, although many 3-year-olds may have some notion of the future, I found very limited evidence that they could apply this notion in contexts other than reflecting on the uncertainty of immediate future events.

The ability of many 3-year-olds to spontaneously prepare for alternative futures on Chapter 6’s forked tube task may have parallels with the finding that same-aged children can reason counterfactually about very recent past events. Many 3-year-olds, for example, understand that a messy floor would have remained clean if a character had taken their dirty shoes off before walking on it (Harris, German, & Mills, 1996). Indeed, the ability to reflect on past alternatives may require many of the same cognitive components as the ability to reflect on and prepare for future alternatives. But if many 3-year-olds can reflect on temporally-removed representations, then why do they struggle to show flexible future-oriented behaviour in other contexts? This is an important question for future research, and one candidate is a general deficiency in executive functions compared to older children. As described in the executive producer section of Chapter 2, many future-oriented behaviours necessarily require an ability to inhibit present-oriented action. This may be particularly difficult for young children, given the typically weak salience of future representations when compared to perceptions of current reality. Several studies have found fundamental shifts in executive functions between ages three and four (see, e.g., Carlson, Davis, & Leach, 2005; Diamond & Taylor, 1996; Espy, 1997; Gerstadt, Hong, & Diamond, 1994; Zelazo & Carlson, 2012), as children become increasingly competent in their ability to inhibit automatic action according to complex novel rules.

**Four-year-olds**

Four-year-old children were tested in all of the empirical chapters’ studies. Consistent with Chapter 2’s review, they demonstrated some level of success on most of the tasks. The large majority of 4-year-olds were able to spontaneously prepare for alternative future outcomes in Chapter 6, suggesting that children may well and truly possess a metarepresentational notion of future representations by this age. In Chapter 3, 4-year-olds demonstrated an ability to apply this concept by selecting an appropriate item that could solve a deferred future problem. Moreover, in Chapter 5, the majority of 4-year-olds demonstrated an ability to carry out a prospective intention in the presence of an external cue, suggesting they possess the capacity to retain future intentions.
when engaged in secondary ongoing tasks. These findings add to the growing body of literature regarding the future-oriented cognitive and behavioural competencies of 4-year-olds, and are consistent with the view presented in Chapter 2 that initial developments in all of the central episodic foresight components are seen by this age.

This is not to say, however, that 4-year-olds performed well on all tasks, consistent with the view that certain future-oriented behaviours may develop later than others due to differential loads placed on the relevant episodic foresight components. For example, despite their strong performance on Chapter 5’s prospective memory task when the event-based cue was available, only 8.3% of 4-year-olds could carry out the future intention without the cue. Furthermore, 4-year-olds as a group showed no evidence of being able to seek and retain information for a specific future episode when low-level associative explanations were controlled for in Chapter 4’s studies. The 4-year-olds’ difficulties with the internally-demanding prospective memory task and the future-oriented information seeking tasks could potentially be explained by a limited propensity to engage in doubly embedded mental time travel (see earlier), which would allow them to reflect on how they will need to use their memory in the future. The general ability to generate multiple levels of recursive embedding (Corballis, 2007, 2011; Dennett, 1983; Dunbar, 2008) may therefore be one important sub-component typically lacking from 4-year-olds’ mental time travel. Levels of recursive embedding may be fundamentally constrained by limits in working memory capacity, as multiple representations and the relations between them must be held in mind simultaneously (see Halford, Wilson, & Phillips, 1998; Read, 2008; Suddendorf, 2013). And indeed, working memory capacity appears to increase in a linear fashion well beyond the fourth year (Alloway, Gathercole, & Pickering, 2006).

**Five-year-olds**

Five-year-old children were tested in Chapter 4 and 5’s studies. In Chapter 5’s prospective memory task, nearly all 5-year-olds demonstrated an ability to carry out a future intention in the presence of an external cue, suggesting they are proficient at retaining such intentions when engaged in other activities. And, unlike 4-year-olds, a substantial proportion of 5-year-olds (37.5%) demonstrated a capacity to carry out the future intention in the absence of the cue, suggesting they were able to internally rehearse the intention. Also unlike 4-year-olds, 5-year-olds as a group demonstrated compelling evidence of future-oriented information seeking and encoding across two structurally distinct tasks in Chapter 4. These results suggest that many 5-year-olds have the capacity to reflect on how their memory will be useful in the future and use this information to guide their behaviour in the present. As described earlier, this developmental trajectory is consistent with findings suggesting that children also begin to demonstrate a capacity for doubly embedded cognition around age five in other domains (Mahy & Moses, 2011; Miller, 2009;
Sullivan, et al., 1994; Weisberg & Beck, 2010, 2012). Nevertheless, it must be noted that 5-year-olds did not perform anywhere close to ceiling levels on my tasks requiring this capacity, and so future research may wish to examine the performances of children as they continue to move through the early schooling years.

The future-oriented behaviours measured in Chapter 4 and 5’s studies are of course not the only ones that may begin to emerge later than the fourth year. As described in Chapter 2’s review, for example, 5-year-olds but not 4-year-olds were able to perform above chance on tasks requiring them to reason about future event sequences (McColgan & McCormack, 2008; McCormack & Hanley, 2011). Specifically, they were able to place an item in a location that would assist a character in achieving a future goal, instead of a location where the character would have already missed their chance to achieve the goal. This finding suggests that developments in the set component of episodic foresight continue beyond the fourth year (also see Busby Grant & Suddendorf, 2009; W. J. Friedman, 2000). More generally, it reminds us that improvements in future-oriented behaviour from age five onwards are not just due to increases in levels of recursive embedding, but also due to many other (potentially independent) changes in the critical episodic foresight components.

**Revisiting the Theatre Metaphor**

Having developed, tested, and considered the results from several novel measures of future-oriented behaviour in children, it is now appropriate to revisit the theatre metaphor of episodic foresight (Suddendorf & Corballis, 2007) introduced in Chapter 2. In particular, it may be useful to evaluate whether it has been effective, and also to examine whether any additions or alterations should be made to the theatrical components.

The theatre metaphor aided my investigation into a vast (and underexplored) field by providing a useful framework in which to interpret and design empirical studies. In all seven theatrical analogues I found distinctive material to review, and indeed, aspects of all seven analogues were examined by my novel measures. Chapter 3’s two-room task placed demands on the stage, playwright, set, and actor analogues, as the children had to imagine an event from a removed spatial and temporal context in which they would use their selected item to solve the problem. This task also involved the executive producer and broadcaster analogues, as children had to inhibit their natural preferences when choosing the correct item and were also invited to express the reason for their choice. The two-room tasks in Chapter 4’s Study 1 placed similar demands on the stage, playwright, set, and executive producer analogues, while also placing novel demands on the actor analogue as children had to consider how their future selves would rely on memory to solve a problem. Chapter 4’s Study 2 task required these same components, although it relaxed demands on the stage, playwright, and set analogues because the future-oriented behaviour
occurred in the same context as the future problem. Chapter 5’s task similarly reduced the demands on these analogues, and the results suggested that the executive producer component may have been particularly important in children’s ability to carry out a future intention in the absence of a cue. Chapter 6’s task again relaxed demands on the stage, playwright, and set analogues, while critically testing the director and executive producer analogues as children had to consider and prepare for alternative future outcomes.

One useful addition to the metaphor may be the concept of doubly embedded mental time travel, first introduced in Chapter 4 and referred to several times throughout this general discussion. Doubly embedded mental time travel could be considered analogous to the theatrical plot device known as the ‘play-within-a-play’. Shakespeare famously used this device in Hamlet, in which Prince Hamlet writes and showcases a play he calls The Mousetrap in order to determine the guilt of his uncle in the murder of his father. Likewise, humans often reflect on how their future selves will reflect on or use information encountered in the relative past (and more generally embed information from one temporal context into another). As suggested above, this capacity could be regarded as the role of an actor in the metaphor, considering that it involves reflecting on one’s own future mental state. Nevertheless, in order to embed an entire ‘play’ within an actor’s mind, the playwright must also have direct access to all of the other theatrical analogues, and the director may play a crucial role in comparing and evaluating doubly embedded scenarios.

It is important to remember that the theatrical analogues are just that—analogues—and they should not be mistaken for discrete capacities, modules, or worse, homunculi. Rather, they simply refer to the diverse roles that must be played by various cognitive processes if episodic foresight is to fulfil its function of producing flexible future-oriented behaviour. The measures introduced in my thesis assessed aspects of all these roles, and my interpretation of the results establishes the existence of at least one novel way in which the roles can combine. The roles may be performed by numerous cognitive capacities working in concert (see Chapter 2), and some of these capacities may have an overarching function in several roles.

**The Function of Metarepresentational Insight**

One capacity that may have an overarching function is the ability to form metarepresentations, which I discussed at length in Chapter 7 as a potentially uniquely human component of episodic foresight. In Chapter 2 (and Suddendorf and Corballis’ original exposition of the metaphor), this capacity was considered mainly in the context of the actors and director analogues, because it allows us to understand that our own and others’ future mental states can be inconsistent with those from the present, and it also allows us to generate and reflect on alternative future events. A more inclusive analysis, however, also highlights the potential involvement of metarepresentations in all of the other metaphorical theatre’s analogues (see Table 1).
In their review and discussion of future-oriented behaviour in non-human animals, Suddendorf and Corballis (2007) proposed the ‘multiple limits hypothesis’, which claims that animals may be limited in one or more of the episodic foresight components outlined in the theatre metaphor. In Chapter 2 I extended this hypothesis to young children, whose deficits in one or more of the components could explain their inability to demonstrate certain future-oriented behaviours available to older children and adults. What I hope to have established in Table 1 (and implicitly in Chapter 7), however, is that metarepresentational insight may have a crucial function in all of the components. If so, then without this capacity, young children and non-human animals would be severely limited in their ability to imagine, prepare for, and actively shape specific future events (also see Suddendorf & Corballis, 1997). Tasks like the one introduced in Chapter 6 may therefore be particularly important as future research tries to narrow down just how present-oriented infants become prudent older children, and why non-human animals show such little evidence of flexible future-oriented behaviour.

### Table 1
**Potential Function of Metarepresentational Insight in Each Theatrical Analogue**

<table>
<thead>
<tr>
<th>Theatrical Analogue</th>
<th>Potential function of metarepresentational insight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage</strong></td>
<td>Allows the stage be represented <em>as</em> a stage (a representational mind) on which a virtual ‘play’ (a representation) occurs.</td>
</tr>
<tr>
<td><strong>Playwright</strong></td>
<td>Allows the virtual play to be written (imbued with imaginary content) with the explicit understanding of <em>what</em> is being written (a purely imaginary scenario).</td>
</tr>
<tr>
<td><strong>Set</strong></td>
<td>Allows representation of the future representational perspective, which enables the imaginary scenario to be embedded within a particular future context relative to current reality (see Chapter 7).</td>
</tr>
<tr>
<td><strong>Actors</strong></td>
<td>Allows the understanding that one’s own and others’ future mental states can be inconsistent with those from the present.</td>
</tr>
<tr>
<td><strong>Director</strong></td>
<td>Allows the understanding that single future events can have multiple possible outcomes (see Chapter 6), which is a crucial first step before deciding which version of the future to pursue.</td>
</tr>
<tr>
<td><strong>Executive Producer</strong></td>
<td>Allows explicit knowledge of how present actions can shape a particular (represented) future event.</td>
</tr>
<tr>
<td><strong>Broadcaster</strong></td>
<td>Allows the understanding that rough copies of the imagined future scenario can be transferred into the minds of others.</td>
</tr>
</tbody>
</table>
The capacity to form metarepresentations can be considered as one instantiation of the more general ability for recursive mental operations, because it involves a procedure that calls itself (i.e., a representation calling a representation). One could therefore make the case that it is not metarepresentational insight *per se* that is responsible for the functions outlined in Table 1, but rather the recursive faculty that permits metarepresentations to be formed. Consistent with this idea, Corballis (2007, 2011) has extensively argued that recursion may be the critical element separating human minds from those of other animals, and older preschooler minds from those of younger preschoolers. Recursive operations are crucial not just in forms of mental scenario building like mental time travel and theory of mind (Suddendorf, 2013), but also in other domains with potentially uniquely human elements, such as language, number and music (Chomsky, 1965; Hauser, Chomsky, & Fitch, 2002).

Metarepresentational insight (and recursion more generally) may be necessary for many of the episodic foresight components to function normally, but it is certainly not sufficient. Other capacities undoubtedly also play overarching roles in many of the theatrical analogues. It is hard to imagine how any of the components could function well, for instance, without sufficient working memory capacity to bring to mind and manipulate offline information. And more specifically, the *broadcaster* component would be useless if humans were not motivated to share imagined scenarios with others (Suddendorf, 2013; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Indeed, I am not claiming that metarepresentational insight is the one and only ‘magic ingredient’ in episodic foresight. Rather, I simply wish to point out the limitations potentially faced by agents lacking this capacity, which could provide a framework for designing and interpreting empirical research.

**Potential Limitations**

My thesis, like any academic work, is not without potential limitations, and I have attempted to discuss and address these throughout the body chapters. Nevertheless, there are two more general issues worth explicitly mentioning here. The first issue regards my empirical questions, which were largely concerned with what future-oriented behaviours emerge *when*, rather than *why*. Indeed, although the data permit firm conclusions about the development of four future-oriented behaviours (acting for deferred future episodes, future-oriented information-seeking, time-based prospective memory, and preparing for alternative future outcomes), they do not permit firm conclusions about the episodic foresight components that were driving the developments. In this general discussion I have attempted to outline the components that may have been particularly crucial for each task, but it should be reiterated that these are hypotheses only, rather than statements of fact. The benefit of my approach, however, is that it has opened four domains of enquiry into the *why* of future-oriented behaviour development, instead of just one. As described throughout the current chapter, there now exist numerous opportunities for future research into the
mechanisms of developmental change for each experimental task. These opportunities would not have been so numerous were my thesis to have taken an alternative approach.

The second potential limitation concerns whether the successful child participants were truly representing the consequences of their behaviours as being located in the future. Throughout the studies in chapters 3-5, I attempted to necessitate the use of episodic foresight by including sand-timers that marked when in the future the children’s behaviour would have an effect. It remains conceivable, however, that some children were able to pass using simpler, atemporal strategies. This problem is shared by much of the research reviewed in Chapter 2, as many ostensibly future-oriented behaviours can be explained by low-level cues, associative learning mechanisms (see, e.g., Suddendorf, Corballis, & Collier-Baker, 2009), or uncontextualised representations of familiar/novel events (see Chapter 7). One way that future research could potentially resolve this issue would be to introduce non-temporal control conditions and examine whether the children’s performance declined when the requirement to use episodic foresight was added. Nevertheless, it is difficult to imagine how such control conditions could remain exactly equivalent to the future-oriented conditions on all non-temporal dimensions (e.g., the conditions would likely have distinct language demands). Alternatively, instead of requiring children to simply act on the basis of future representations, one could take the metarepresentational approach of assessing what children know about future representations (e.g., do they know that such representations can be misleading?). The forked-tube task introduced in Chapter 6 goes at least some way towards assessing this capacity, and the results appear to suggest that most children represent something about the nature of future representations from the fourth year onwards.

**Conclusion**

In conclusion, my thesis has made many novel contributions to the theoretical, developmental, and comparative episodic foresight literatures. I have provided the first developmental review of the critical cognitive components implicated in episodic foresight and the future-oriented behaviours these components enable. I have developed and implemented several novel measures of future-oriented behaviours, with the results substantiating the claim that crucial developmental milestones in episodic foresight are achieved throughout the preschool years. The overall findings also support the proposal that different future-oriented behaviours develop at different ages because they place different loads on the various cognitive components. On another note, I have demonstrated the potential for sharing experimental methods between developmental and comparative psychology, by creating a nonverbal paradigm useful for measuring the future-oriented capacities of both children and non-human primates. Finally, I have provided a novel theoretical proposal that may explain much about why children eventually become capable of many future-oriented behaviours that appear out of reach for other animals.
In many ways, my thesis provides only the first step towards understanding certain aspects of episodic foresight and future-oriented behaviour. The experimental methods and ideas contained herein may lay the foundation for much further work in developmental psychology and other domains. Indeed, I hope that my thesis contributes considerably towards shaping the future of future-oriented psychological research.
References


Hudson, J. A. (2002). "Do you know what we're going to do this summer?": Mothers' talk to preschool children about future events. *Journal of Cognition and Development, 3*(1), 49-71.


Rafetseder, E., & Perner, J. (2012). When the alternative would have been better: Counterfactual reasoning and the emergence of regret. *Cognition and Emotion, 26*(5), 800-819.


